PROVINCE OF NEWFOUNDLAND AND LABRADOR
OFFICE OF CLIMATE CHANGE AND ENERGY EFFICIENCY

IMPROVING RESILIENCE TO CLIMATE CHANGE IMPACTS

CASE STUDY REPORT
MAIN STREET BRIDGE, CORNER BROOK

Report No.: TP114024-001

Prepared for:

Province of Newfoundland and Labrador
Office of Climate Change and Energy Efficiency
P.O. Box 8700
St. John's, Newfoundland and Labrador
Canada, A1B 4J6

Prepared by:

AMEC Environment & Infrastructure
(a Division of AMEC Americas Limited)
3215 North Service Road
Burlington, Ontario
Canada, L7N 3G2

March 2015

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APPROVALS

Prepared by: Peter Nimmrichter, M.Eng., P.Eng.
Senior Water Resources Engineer &
Climate Change Specialist

March 31, 2015
Date

Reviewed by: Brian Bishop, M. Eng., P. Eng
Senior Associate Engineer

March 31, 2015
Date

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EXECUTIVE SUMMARY

Infrastructure, whether built, human or natural, is critically important to individuals and communities. The purpose of infrastructure is to protect the life, health, and social welfare of all of its inhabitants from the weather elements, to host economic activities and to sustain aesthetic and cultural values. When infrastructure fails under extreme weather conditions and can no longer provide services to communities, the result is often a disaster. As the climate changes, it is likely that risks for infrastructure failure will increase as weather patterns shift and extreme weather conditions become more variable and regionally more intense. Since infrastructure underpins so many economic activities of societies, these impacts will be significant and will require adaptation measures. Even though municipalities share responsibilities associated with infrastructure with other levels of government, any effect of climate change is ultimately experienced locally, even if its origins are outside local jurisdictions, such as disruption of electrical power or fuel supply.

The degree to which a municipality is able to deal with the impact of climate change is often referred to as “adaptive capacity” or “the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with consequences” (Intergovernmental Panel on Climate Change, 2001). The vulnerability of infrastructure systems needs to be assessed as part of municipal risk management and decision making. Understanding the level of vulnerability also contributes to better, more informed decision-making and policy development by providing a basis for establishing priorities.

A key aspect of the Government of Newfoundland and Labrador’s 2011 Climate Change Action Plan was to establish the Office of Climate Change and Energy Efficiency (CCEE) as a central agency located in Executive Council to lead policy and strategy development on issues relating to climate change and energy efficiency. The Office works collaboratively with other departments and agencies to ensure the subjects of climate change and energy efficiency are effectively integrated into policy development and decision making. The CCEE assists with development and better use of climate change data for the Province and consideration of how climate change will impact infrastructure. The Province has been and continues to make efforts towards maximizing the use of the available data sets, covering areas of climate variable projections, flood risk mapping, coastal vulnerability and sea level rise, to inform better planning and decision making, ultimately increasing the Province’s resilience to the potential impacts of climate change.

Engineers Canada established the Public Infrastructure Engineering Vulnerability Committee (PIEVC) to oversee a national engineering assessment of the vulnerability of Canadian public infrastructure to changing climate conditions. PIEVC developed a protocol in 2005 to guide vulnerability assessments. The Protocol is a procedure to systematically gather and examine available data in order to develop an understanding of the relevant climate effects and associated interactions with infrastructure.

This project was developed by the CCEE, with funding support from the Province of Newfoundland and Labrador, Department of Environment and Conservation, to support the demonstration of the PIEVC Protocol towards a better understanding of potential vulnerabilities of Provincial infrastructure from climate change and to develop educational material to support two climate change workshops held in June 2014 in St. John's. These workshops were attended by about 120 government decisions makers, engineers, planners, municipal staff and other stakeholders.

The climate change vulnerability assessments which have been completed are founded on version 10 of the PIEVC Protocol and Provincial climate change datasets and targeted three (3) case study sites in Newfoundland, namely:

- Corner Brook – Main Street Bridge over Corner Brook Stream
- Goulds – Stormwater management and storm sewer design
- Placentia – Laval High School

These climate change risk assessments have been developed as demonstration projects / case studies and as such do not apply all aspects of the PIEVC Protocol. These assessments have focused only on Steps 1, 2 and 3 of the Protocol, although some recommendations (Step 5) stemming from the assessment are offered. Step 4 (Engineering Analysis) was not included in these assessments.

This report constitutes the final documentation regarding the climate change vulnerability assessment of the Main Street Bridge in Corner Brook.

Recommendations stemming from the application of the PIEVC Protocol to the Main Street Bridge in Corner Brook to assess risks and vulnerabilities to projected changes in climate phenomenon in the future are outlined below.

- It is recommended that near term changes in the expected frequency of freeze thaw cycles be evaluated to determine the effects of potential increased cycles on bridge wearing surfaces.
- It is recommended that scour at the bridge be periodically monitored.
- It is recommended that the data referenced in the applicable design codes and guidelines be updated to reflect current information. Alternatively, a mechanism to require completion of a site-specific climate assessment to determine whether in-depth analysis is necessary for infrastructure being designed or evaluated be developed.

- It is recommended that recording of climatic events specific to the subject infrastructure be a regular procedure in the administration of the infrastructure.
- It is recommended that the climate change projections available from the Province be augmented such that the time series upon which the projections area based are made available such that more in-depth interrogation of the datasets is possible.
- It is recommended that this scoped climate change vulnerability assessment be completed in full for all components (referring to Steps 1 to 5) of the PIEVC protocol.[1]

General recommendations regarding climate change risk assessment of infrastructure stemming from the workshops included:

- The Province should develop procedures and/or policies for incorporating risk assessment into infrastructure planning and development practices.
- The development of climate change datasets by the Province is a great step forward in breaking down perceived barriers to climate change risk assessments. However, barriers that still exist as a consequence of the lack of coordination among departments and lack of understanding of the “do nothing” scenario still need to be addressed. As such, better Government interdepartmental coordination should be advanced towards a consistent view of the requirements for incorporating risk assessment into infrastructure planning and development practices.
- The workshops clearly demonstrated value in advancing understanding of climate change issues affecting infrastructure in the Province. Further opportunities for training/education about climate change and the potential impacts to the Province should be continued for all levels of government and the private sector.
- The climate change datasets developed by the Province can generally support climate change risk assessment. However, the Province should not view these datasets as static. Examples of gaps in the datasets have already been noted (i.e., short duration IDF data). With changing science and data collection new projections are being developed around the world. The Province should develop a review cycle for its datasets. Further, the Province should also allow for new datasets to be analysed and incorporated into the larger suite of datasets.

[1] Adoption of this recommendation would encompass some of the other recommendations itemized in the list.

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SECTION 1

INTRODUCTION

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1 INTRODUCTION

It has been projected that Newfoundland and Labrador (the "Province") may, in the future, experience changes in the frequency and/or severity of extreme weather as well as changes to average climate over several decades or more as a result of climate changes. These changes are expected to affect natural, social and built infrastructure, potentially having significant socio-economic consequences. The climate change assessment focus has most often been directed towards a range of mitigation options related to energy use. These have been targeted at reducing greenhouse gas emissions, encouraging public transport and increasing energy efficiency at all scales in the community. However, more recently, the focus has shifted toward adaptation measures recognizing that communities must adapt to changing climatic conditions.

The Government of Newfoundland and Labrador has recognized the potential for change in the Province and has charted a course for the Province with the 2011 Climate Change Action Plan which establishes the provincial Government's strategic approach to climate change. As a component of this strategy the Office of Climate Change and Energy Efficiency (CCEE) was initiated as a central agency located in Executive Council to lead policy and strategy development on issues relating to climate change and energy efficiency. As a key part of this mandate, the Office works collaboratively with other departments and agencies to ensure the subjects of climate change and energy efficiency are effectively integrated into policy development and decision making.[2]

A component of the CCEE's mandate is directed towards development and better use of climate change data sets available for the Province and consideration of how climate change will impact infrastructure. The Province has been and continues to make efforts towards maximizing the use of the data sets that have been developed, covering areas of climate change projections, flood risk mapping, coastal vulnerability and sea level rise, to inform better planning and decision making, ultimately increasing the Province's resilience to the potential impacts of climate change.

Engineers Canada, the business name of the Canadian Council of Professional Engineers, established the Public Infrastructure Engineering Vulnerability Committee (PIEVC) to oversee a national engineering assessment of the vulnerability of Canadian public infrastructure to changing climate conditions. PIEVC developed a protocol in 2005 to guide vulnerability assessments. The Protocol is a procedure to gather and examine available data in order to develop an understanding of the relevant climate effects and their interactions with infrastructure.

This project was developed by the CCEE to support the demonstration of the PIEVC Protocol towards a better understanding of potential vulnerabilities of Provincial infrastructure from

[2] From http://www.exec.gov.nl.ca/exec/ccee/

climate change and to develop educational material to support two climate change workshops held in June 2014 in St. John's, namely:

- One (1) - ½ day workshop for Decision-Makers on Integrating Climate Risk into Infrastructure Decisions in Newfoundland and Labrador, held on June 3rd, 2014, and,
- Two (2) - one (1) day workshops for Engineers, Planners and Municipal staff on Integrating Climate Risk into Infrastructure Decisions in Newfoundland and Labrador, was held on June 4th, 2014. The second one day workshop was held on June 5th, 2014.

These climate change vulnerability assessments are founded on version 10 of the PIEVC Protocol and Provincial climate change datasets and targeted three (3) case study sites in Newfoundland, namely:

- Corner Brook – Main Street Bridge over Corner Brook Stream
- Goulds – Stormwater management and storm sewer design
- Placentia – Laval High School

As noted above, these climate change risk assessments have been developed as demonstration projects and as such do not apply all the steps of the PIEVC Protocol.

Separate reports have been developed for each of the climate change vulnerability assessments completed for the infrastructure sites noted above. This report constitutes the final documentation regarding the climate change vulnerability assessment of the Main Street Bridge in Corner Brook.

1.1 PROJECT OBJECTIVES

The principal objective of this study is to identify those components of the Main Street Bridge that are at risk of failure, damage and/or deterioration from extreme climatic events or significant changes to baseline climate design values. The nature and relative levels of risk are to be determined in order to establish priorities for remedial action. The assessment of vulnerability was based on the May 2012 (v10) PIEVC Protocol, premised on potentially three (3) future time frames, namely: 2020, 2050 and 2080 where data was available.

The outcomes of all of the assessments are expected to drive possible remedial action at the study-specific infrastructure locations and to support CCEE efforts to engage the engineering community and advance risk based design for infrastructure in the Province. Further, the results of this assessment will be incorporated into the national knowledge base which has been formed as a basis for analysis and development of recommendations for review of codes, standards and engineering practices.

1.2 PROJECT SCOPE

This scoped climate change vulnerability assessment has been developed as demonstration projects / case study and as such do not apply all aspects of the PIEVC Protocol. The assessment focuses only on Steps 1, 2 and 3 of the Protocol, although some recommendations (Step 5) stemming from the assessment are offered. Step 4 (Engineering Analysis) was not included in these assessments. This vulnerability assessment has been based on version 10 of the Protocol.

The intent of this assessment is to provide an overview of the PIEVC Protocol and, and through an example, how its application to infrastructure can assist in understanding risks in the face of a changing climate. Further, this report provides only a preliminary risk assessment of the Main Street Bridge in the City of Corner Brook, in essence, a starting point. As a starting point, it does not touch on all aspects of the infrastructure or all potential climatic influences. Full applications of the PIEVC Protocol have been completed for similar infrastructure elsewhere in Canada. These reports are available at the PIEVC website (www.pievc.ca) and it is encouraged that these be reviewed in advance of a more in-depth risk assessment of the Main Street Bridge in the future.

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SECTION 2

PIEVC PROTOCOL STEP 1

PROJECT DEFINITION

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2 STEP 1 - PROJECT DEFINITION

2.1 OVERVIEW

Step 1 of the PIEVC Protocol focuses on the development of a general description for the following aspects of the project:

- location of the vulnerability assessment;
- infrastructure of concern;
- historic climate;
- existing loads on the subject infrastructure;
- age of the subject infrastructure;
- other relevant factors;
- identification of major documents and information sources.

The outcome from this step is a definition of the boundary conditions for the vulnerability assessment.

2.2 STUDY LOCATION

The City of Corner Brook ("Corner Brook") lies on the western side of the island of Newfoundland (ref. Figure 2-1 and Figure 2-2). The community covers a geographic area of about 150 km^2 and lies at an elevation between 0 m and about 300 m above sea level. General land slopes across the community average about 2%. Soils in the area are generally classified as moraine/till material deposited by glacial ice, namely a mixture of boulders, sand, silt, and clay.

The population of Corner Brook was 19,886 in 2011, representing a decrease from 2001 of about 1%. The population decrease for the community is expected to continue with 2021 projected population of -4.8% lower than 2006 or 19,119. Extrapolating this data to the future suggests the population of Corner Brook in 2050 will probably be less than today's population. Linear trending of population data since 1970 suggests a population of about 13,000 in 2050, whereas trending since 2001 suggests a population of about 19,000 in 2050; a wide range but a general trend of somewhat stable or decreasing population in Corner Brook into the future.

Corner Brook Stream, and its main tributary Bell's Brook, are the major watercourses which traverse the city (ref. Figure 2-3).

Figure 2-1: Study Location - Regional Context

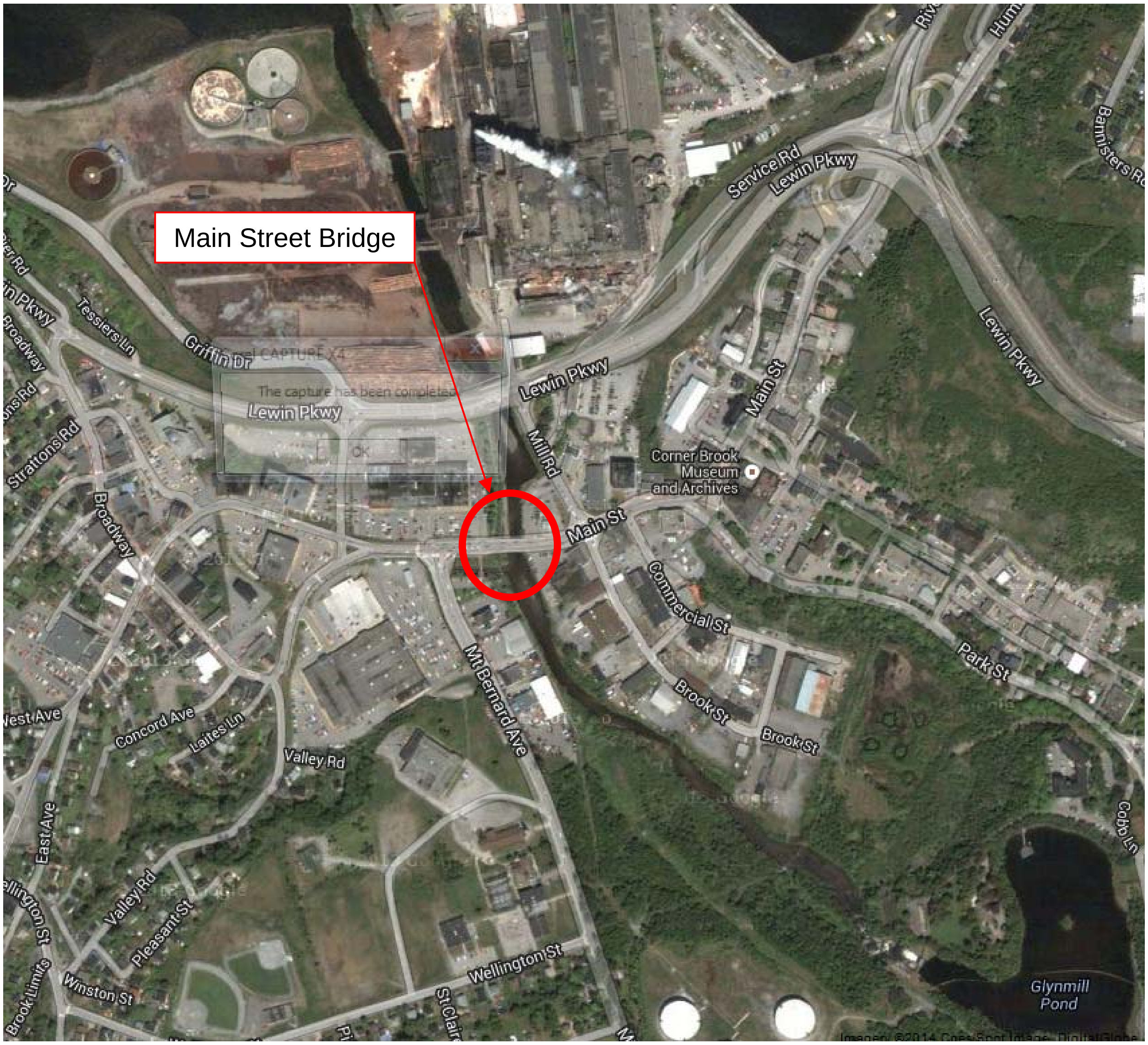

Figure 2-2: Study Location – Local Context

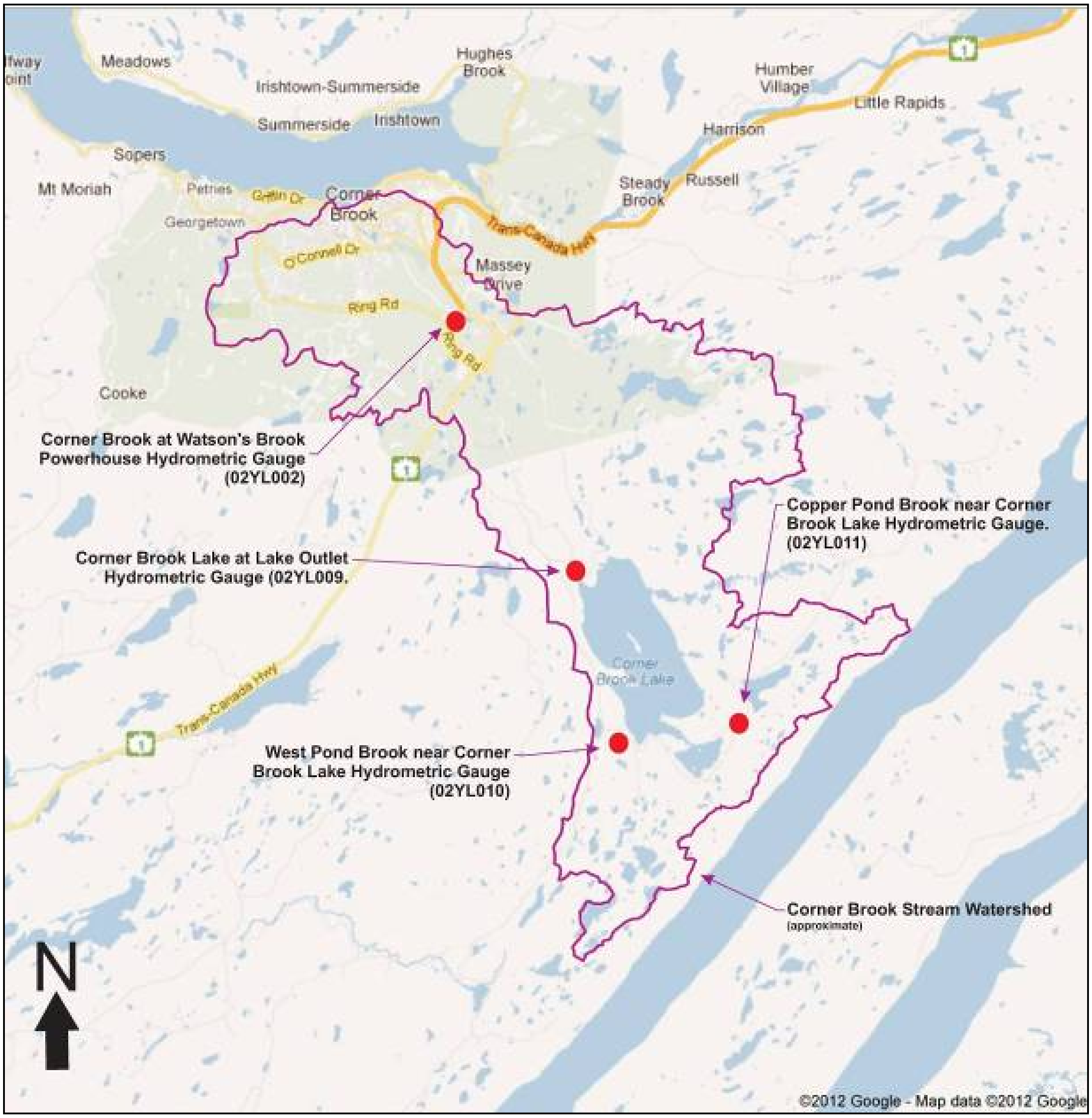

Figure 2-3: Corner Brook Stream Watershed
(source: AMEC, 2013)

2.3 STUDY INFRASTRUCTURE

The study infrastructure for this climate change vulnerability assessment is the Main Street Bridge in Corner Brook. The bridge is located in the core of the City at the following co-ordinates:

Easting	345141.1
Northing	5423865.6
Control	NAD83
Projection	MTM Zone 3

The bridge was re-constructed in 1957 to its present form and Main Street is presently designated as a collector road.

Specific information regarding existing traffic loads for the Main Street Bridge was not available for this assessment.

It is noted, however, in a 2003 inspection report by the Department of Works, Services and Transportation, Highway Design Division (DWST) that there was evidence of excessive loads having traversed the bridge resulting in damage to the structure.

As noted previously, the Main Street Bridge traverses the Corner Brook Stream. Flood plain mapping was prepared for Corner Brook Stream in 2013 (AMEC, 2013). Flood plain mapping from that hydrotechnical study indicates that the Main Street Bridge would be flooded (overtopped) during the 20 year and 100 year floods.

As noted previously, it is understood that this assessment is limited and reflects a preliminary review of the potential for climate change to influence functionality and integrity of the bridge.

During periods of severe weather which could result in flooding, water levels in the Corner Brook Stream at the Main Street Bridge are monitored (as well as other locations in the community). When water levels in Corner Brook Stream rise to within 150mm (6”) of the top of the bridge piers, then the emergency procedure is to close the bridge. Further, as water levels approach that level, this needs to be monitored very closely and even if it is anticipated that water will rise to this level, for example with rising tides, continuing rainfall or planned release of waters by Deer Lake Power from upstream dams, then the emergency procedure is to close the bridge.

2.4 STUDY AREA CLIMATE

The climate of Corner Brook provides four distinct seasons; a fairly warm summer, cool fall, snowy winter, and a short spring. Additional details regarding general climatic trends in the area are available at the City of Corner Brook website[3]. The statistical summaries in Table 2-1 provide a general overview of the study area climate. It is interesting to note consistent increases in average annual precipitation over the three periods noted in Table 2-1.

A complete listing of the climate normals for Corner Brook, for each of the periods noted in Table 2-1, is available via the Environment Canada website.

2.5 OTHER RELEVANT FACTORS

The current design guideline for bridges in the Province is documented in:

> Chapter 4, Environmental Guidelines for Bridges, Water Resources management Division , Water Investigations Section, Department of Environment and Labour, Government of Newfoundland and Labrador, January 12, 1989.

available via http://www.env.gov.nl.ca/env/waterres/regulations/appforms/chapter4.pdf

Table 4.2 from the guidelines (noted above) recommends the 50 year return period flood as the appropriate design basis for design of conveyance under a collector road bridge.

2.6 ASSESSMENT TIME FRAMES

2.6.1 Historical

The time frame used for this assessment for representation of historical information is the period 1981-2010. This 30-year period matches the most recent climate normal period available from Environment Canada. Where independent data analyses were completed for this assessment, the 1981-2010 time frame was used unless otherwise indicated.

2.6.2 Future

It had been planned to complete the vulnerability assessment for three future periods, namely 2020, 2050 and 2080. These future periods reflect the tri-decade periods of 2005-2034, representing 2020, 2035 to 2064, representing 2050, and 2065 to 2094, representing 2080. Gaps in the available climate datasets are noted where they have been identified.

However, vulnerability assessment beyond the 2050 time frame was not completed in consideration of the design life of the subject infrastructure and availability of climate projections. That is, significant reconstruction and/or rehabilitation of the infrastructure would likely occur beyond 2050. It is also understood that the uncertainty associated with climate projections increases moving farther into the future which would limit or question the validity and/or usability of any results.

[3] http://www.cornerbrook.com/default.asp?mn=1.24.344

Table 2-1: Climate Information for Corner Brook[4]

Climate Parameter	1961-1990	1971-2000	1981-2010
Precipitation			
Average annual precipitation	1186 mm	1270.8 mm	1285.8mm
Average annual rainfall	771 mm	848.9 mm	884.5 mm
Average annual snowfall	414.4 cm	422 cm	401.3 cm
Extreme daily rainfall	82.6 mm September 1948	82.8 mm June 1995	
Extreme daily snowfall	61 cm February 1938		
Extreme snow depth	n/a	155 cm February 1988	
Annual occurrence of daily rainfall events (with totals >25 mm)	n/a	4.6 events per year generally between June and October	5.2 events per year generally between May and November
Temperature			
Daily average minimum temperature	1.3 °C	1.2 °C	1.3 °C
Daily average maximum temperature	9.0 °C	8.9 °C	9.0 °C
Extreme minimum temperature	-31.7 °C January and February 1934		
Extreme maximum temperature	34.4 °C August 1936		35.0 °C July 2003
Frost			
Average date of last spring frost	n/a	n/a	May 19th
Average data of first autumn frost	n/a	n/a	October 13th
Average frost free season	n/a	n/a	146

2.7 MAJOR DOCUMENTS AND INFORMATION SOURCES

Major documents and other information sources used to support this climate change vulnerability assessment are referenced, as appropriate, throughout this report.

4 Source: Environment Canada Climate Normals 1981-2010 for the Corner Brook weather station (#8401300), Environment Canada website at http://climate.weather.gc.ca/climate_normals/results_1981_2010_e.html?stnID=6610&lang=e&StationName=corner+brook&SearchType=Contains&stnNameSubmit=go&dCode=4&dispBack=1

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SECTION 3

PIEVC PROTOCOL STEP 2

DATA GATHERING AND SUFFICIENCY

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3 STEP 2 - DATA GATHERING AND SUFFICIENCY

3.1 OVERVIEW

Step 2 of the PIEVC Protocol focuses on describing aspects of the subject infrastructure that will be assessed with relevant climate change parameters. Identification of the infrastructure components to be considered for evaluation has focused on:

- what are the infrastructure components of interest to be evaluated?
- number of physical elements and location(s)
- other potential engineering / technical considerations
- operations and maintenance practices and performance goals

The second part of this task focused on identification of relevant climate information. Climatic and meteorological data (both existing/historic data, as well as, future projected climate data) has been identified and collected. The objectives of the climate analysis and projections component of this assessment are to:

- establish a set of climate parameters describing climatic and meteorological phenomena relevant to the City of Corner Brook, and;
- establish a general probability of occurrence of each climate phenomena, both historically and in the future.

As noted in Section 2, for the purposes of this assessment the term "historical" is defined as comprising both the existing climate and the climate from the recent past, while the "future" climate is defined as representing three timeframes, namely 2020, 2050 and 2080, where data is available.

Given the scoping level nature of this vulnerability assessment, the AMEC Team identified features of the subject infrastructure to be considered in the assessment using the climate information gathered for this study. The development of this assessment framework is typically a collaborative effort between the consultant and infrastructure owner/operator. The infrastructure component data and the climatic data form the foundation of the risk assessment matrix which is a fundamental aspect of the Protocol.

3.2 INFRASTRUCTURE OF INTEREST

As noted previously, the infrastructure of interest for this climate change vulnerability assessment is the Main Street Bridge in the City of Corner Brook in the Province of Newfoundland and Labrador.

3.2.1 Main Street Bridge

The available information suggests that the Main Street Bridge was originally constructed as a one-lane structure in the 1920's as part of the Bowater Pulp & Paper Mill development. The bridge was re-constructed in its present form in 1957 by the Province and incorporated some parts of the old piers as indicated on the drawings. Some rehabilitation of the bridge piers was completed in 2005. The present bridge accommodates two (2) westbound lanes and one (1) eastbound lane.

The bridge, today, is a two (2 x 11.735 m) span simply supported concrete deck on cast in place (CIP) concrete girders. The concrete girders were casted monolithically. The bridge deck is CIP reinforced concrete, also cast monolithically on the concrete girders (T-beams). The support/pier is comprised of a solid, cast-in-place (CIP) reinforced concrete shaft. The bridge has a sidewalk and a concrete railing type of barrier on each side. The bridge has deep foundations comprised of bearing timber piles. The abutments are conventional CIP reinforced concrete. The deck has an approximate thickness of 1.02 m and a minimum top of deck elevation of 3.32m. The upstream and downstream inverts in THE Corner Brook Stream at the bridge are 0.74m and 0.83m, respectively, suggesting some stream bed scour is occurring at the upstream side of the structure. The vertical opening below the bridge obvert is approximately 1.56m.

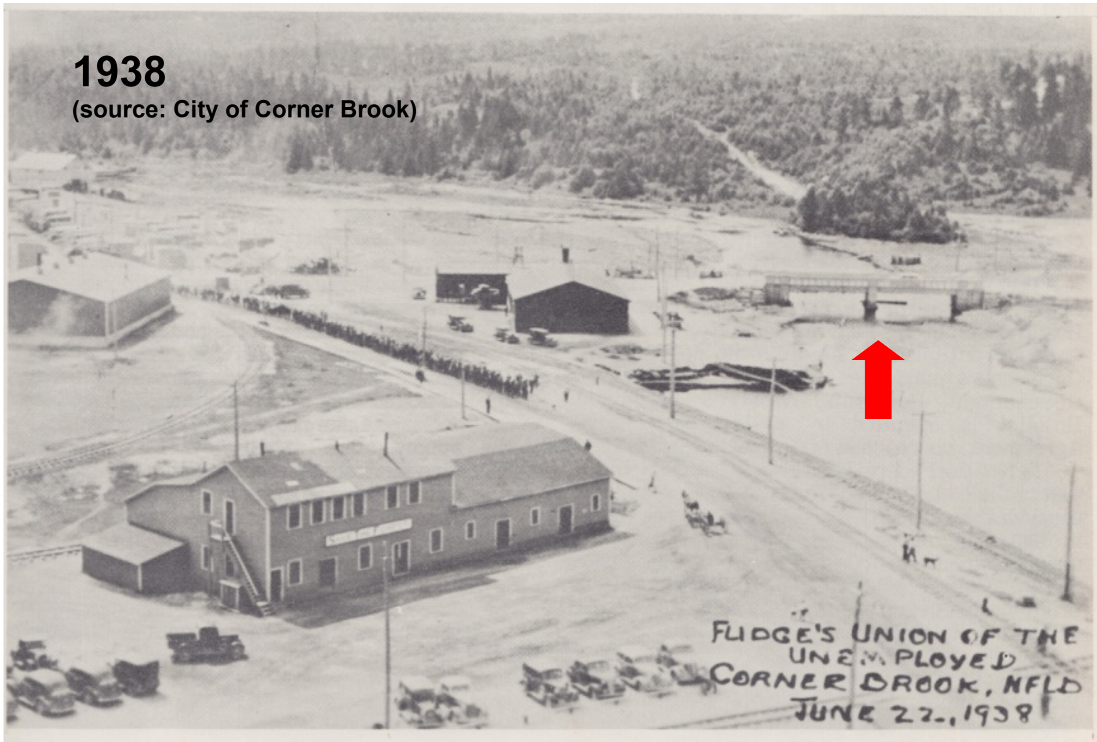
In 2003 an inspection by the Department of Works, Services and Transportation, Highway Design Division (DSWT)[5] noted a number of issues but concluded the bridge to be in fair condition although in need of some rehabilitation.

Another inspection completed in April 2014, by Anderson Engineering Consultants Inc., concluded that the bridge has exceeded its useful life and is in need of "immediate replacement or at the very least extensive repairs".

A number of historical and more recent photos of the bridge are provided on the following pages.

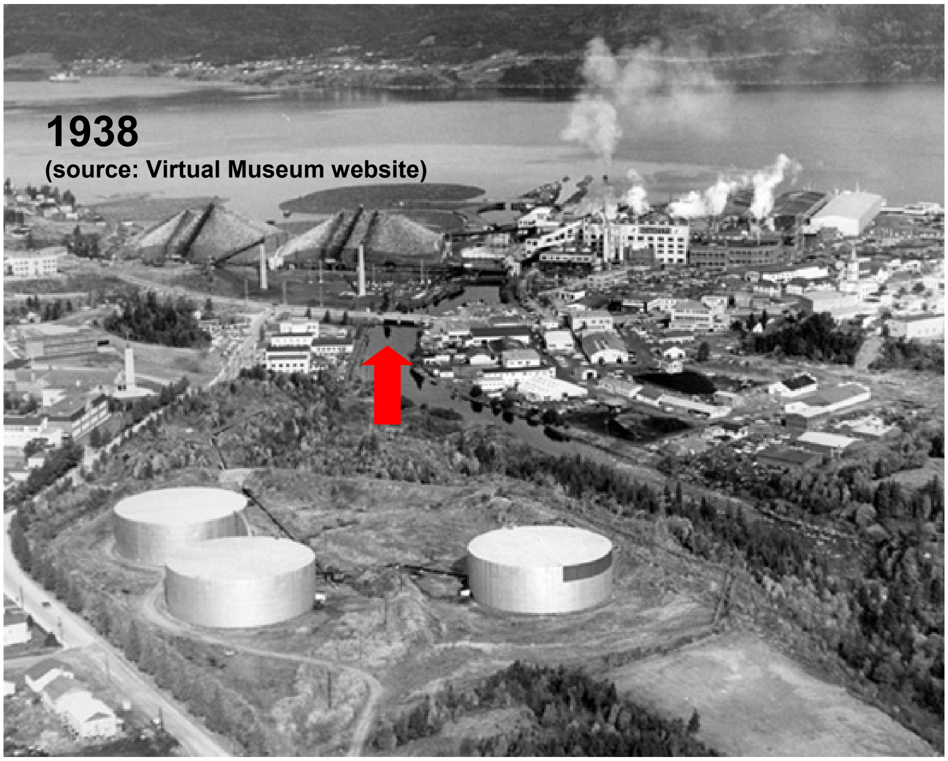
Drawings of the bridge made available from the City of Corner Brook for this assessment are provided in Appendix A.

[5] Renamed the Department of Transportation and Works (DTW) as of 2003

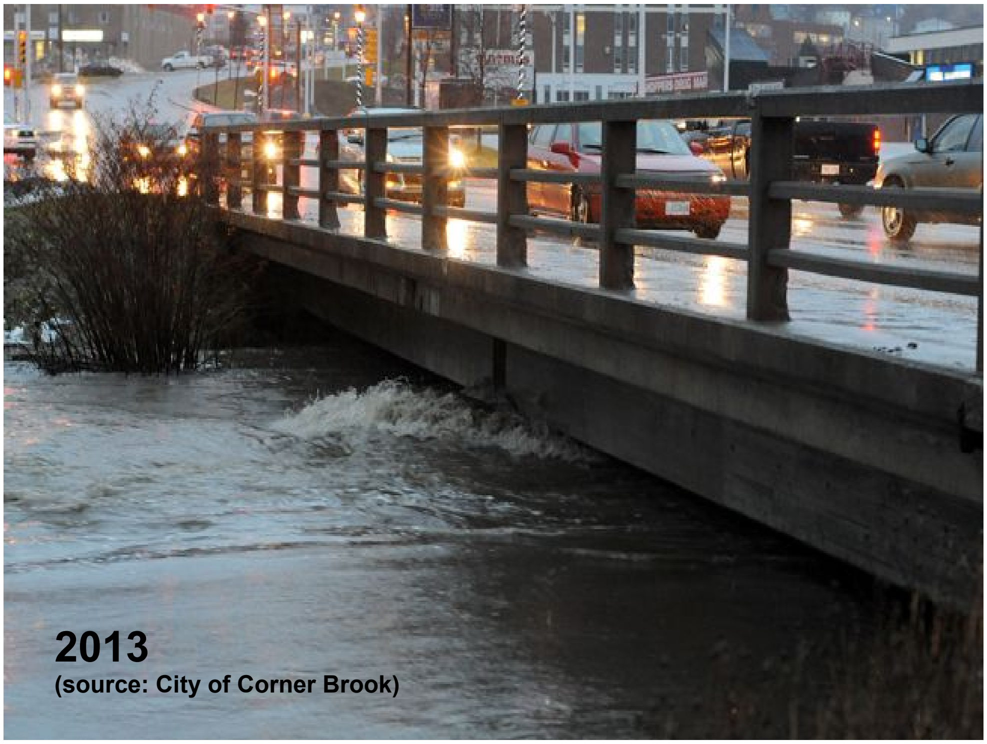


1938
(source: City of Corner Brook)

1956
(source: http://collections.mun.ca/PDFs/guardian/AG_V13N01.pdf **)**


1938
(source: Virtual Museum website)


2011
(source: AMEC, 2013)



3.3 EXISTING LOADS AND COMPONENTS

3.3.1 Structure

The specific design basis which supported the 1957 reconstruction of the bridge is not known.

The City of Corner Brook indicated that recent traffic analysis for the area is not available, but average annual daily traffic is estimated to be in excess of 20,000 vehicles. There are only three (3) crossings of Corner Brook Stream in the City so the Main Street Bridge handles a wide variety of traffic types although heaver truck traffic would normally use the Lewin Parkway or O' Connell Drive crossings. As well, traffic is congested in this area and the City is also considering widening the structure to provide additional capacity.

The 2003 DWST report documented that there is evidence of damage from excessive loads on the bridge.

The 2014 Anderson report completed an analysis of bridge loading with the following conclusion that "if the ability of the concrete girders to support the imposed loading was based on the structural analysis only, it could be concluded that the concrete girders for the Main Street Bridge could safely carry day-to-day traffic including tractor trailer loadings." It is further concluded that “although the girders in perfect condition could possibly carry tractor trailer loads, the bridge due to its present condition may not”.

3.3.2 Flood Conveyance

The current conveyance capacity of the Main Street Bridge is illustrated in Figure 2-4, which provides the stage-discharge rating curve developed as a component of the 2013 flood plain mapping of the Corner Brook Stream (AMEC, 2013).

At present, the bridge has insufficient conveyance capacity with regard to high flows in Corner Brook Stream when compared with the current Provincial standard for collector road bridges (e.g. the 50 year flood).

Further, two of the three crossings (Main Street and Lewin Parkway) of the Corner Brook Stream in the City would be overtopped during the 20 year flood. This is a consideration for emergency planning.

In 2013, the bridge was closed on a number of occasions due to high water and ice floes in the stream.

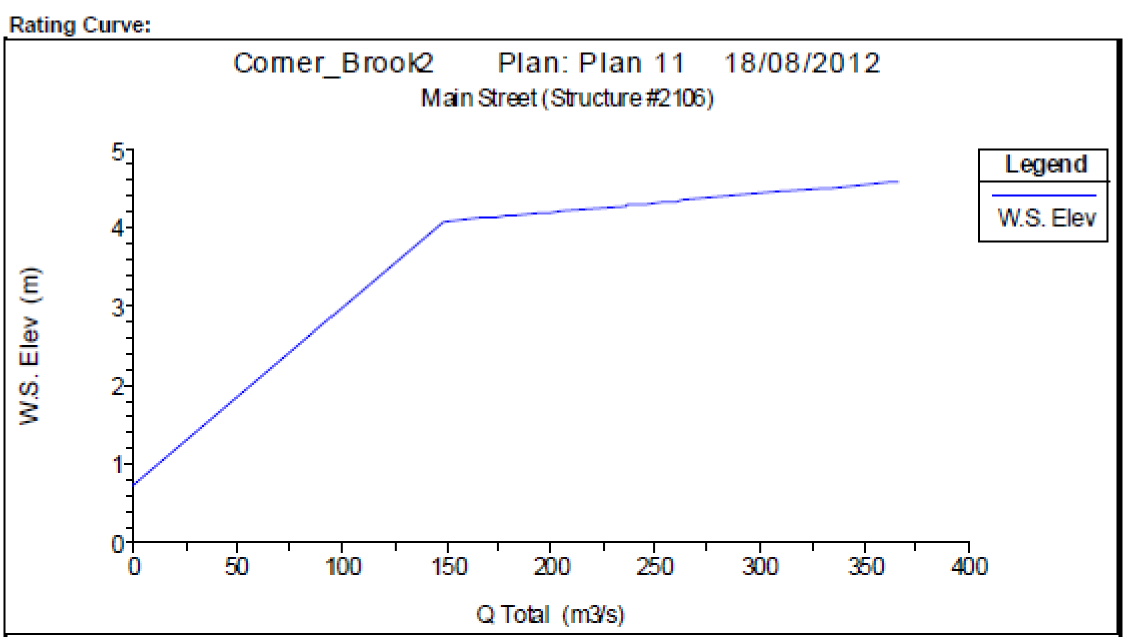


Figure 3-1: Bridge Conveyance Capacity Rating Curve

(source: AMEC, 2013)

3.3.3 Infrastructure Support Systems

- *Power Sources*: Power was not deemed to be a direct element of the subject infrastructure and, therefore, not considered for this assessment.
- *Communications*: Modes of communication include telephone, two-way radio, e-mail, Internet, and telemetry at the WWTP.
- *Transportation*: Transportation refers to the road and driving conditions that can affect operations and staff response time, as well as, adverse conditions that might disrupt normal traffic flow.
- *Personnel*: Consideration was given to staffing situations relevant to operations and maintenance of the subject infrastructure.

3.3.4 Infrastructure Components for Assessment

The study infrastructure has been segregated into the following elemental components for the purposes of assessment:

- Foundation
- Support pier
- Abutments
- Girders
- Bridge deck
- Drainage system
- Operations and Maintenance

3.4 CURRENT DESIGN STANDARDS

If the Main Street Bridge were to be re-constructed the design would follow the Canadian Highway Bridge Design Code (CAN/CSA – S6-06) and would typically include the following elements:

- Girder type of bridge (similar concept to the existing but different construction practices);
- The girders would be either steel I beams or precast pre-stressed concrete CPCI (Canadian Pre-stressed Concrete Institute) girders;
- With slightly deeper girders than the existing, the pier could be eliminated and the bridge would be a single span;
- If pier is required, current design practice would make the bridge continuous over the pier and will eliminate the expansion joint at the pier;

- The bridge would be designed either as an Integral Abutment or Semi-Integral Abutment, in order to eliminate the expansion joints at the abutments;
- Timber piles are no longer used in bridges located on busy highways/roads in urban areas. Current standard is to use steel H-piles or tube piles.

3.5 JURISDICTIONAL OVERVIEW

The Main Street Bridge is owned and managed (including inspections) by the City of Corner Brook.

3.6 CLIMATE ANALYSIS

3.6.1 Overview

The objectives of this component of the report are to:

- Establish a set of climate parameters describing the climatic and meteorological phenomena relevant to the case study
- Establish a general probability of occurrence of each climate parameter both historically and in the future.

As noted previously, the term “historical” relates to climate from the current time frame and recent past while “future” relates to the future time frames previously noted as 2020, 2050 and 2080. However, data for all climate variables/phenomena were not available for these periods.

It should also be noted that this climate analysis is not meant to be exhaustive. The climate information presented in the following sections is not based on new science or analyses generated through this project but a review of readily available information from other sources. It is clear that climate science is advancing rapidly and this review should not be construed as a comprehensive characterization of the historic climate or future projections of the case study.

For this study, the climate change datasets developed by the Province were the primary source of climate data for this assessment. These datasets are described in Section 3.6.2.

As well, uncertainties in the climate projections are clearly demonstrated in the results (Finnis, 2013). The information developed and used for this project is adequate to meet the stated objectives of the case study; however, other potential users of the information should consider it in the proper context.

3.6.2 The "Long" and "Short" List of Climate Variables

A preliminary "long" list of climate parameters was developed based on climate events and change factors identified in Appendix A of the Protocol as indicated below:

- High and Low Temperature
- Heat and Cold Waves
- Extreme Diurnal Temperature Variability
- Freeze Thaw Cycles
- Heavy Rain / Daily Total Rain
- Winter Rain / Freezing Rain
- Ice cover/Thickness
- Coastal Erosion
- Sea Level
- Snow Accumulation
- Blowing Snow/Blizzard
- Frost
- Hail Storm
- Hurricane/Tropical Storm
- High Winds
- Heavy Fog
- Drought/Dry Periods
- Flooding

The list was refined by AMEC[6] based on climatic and meteorological phenomena deemed relevant to the Main Street Bridge in Corner Brook. Further refinement was needed for rainfall oriented parameters to "dovetail" with the available climate projections. Further, the flood plain mapping data that was available for Corner Brook had been developed based on return period rainfall data (both present and future). As such, a review of potential flooding impacts resulting from climate change is encompassed with the review of impacts from potential changes in Extreme Precipitation resulting from climate change. Similarly, a review of potential impacts from Hurricanes/Tropical Storms is addressed with Extreme Precipitation.

Justification for selection of a climate parameter was based on the parameter's potential to affect vulnerability to the infrastructure and its components as a result of either an extreme or persistent occurrence.

The short list of climate variables assessed is outlined below:

- High and Low Temperature
- Heat Waves
- Frost and Freeze Thaw Cycles
- Mean Intensity of Precipitation Events
- Sea Level
- Extreme Precipitation Return Periods
- Maximum 5-day Precipitation

3.6.3 Climate Data Sources

3.6.3.1 Historical

The basic analysis of historical data for the study area was based on data from a variety of sources including:

[6] The refinement exercise is typically done in collaboration with the infrastructure owner/operator

- Environment Canada's Climate Normals

  (available at http://climate.weatheroffice.gc.ca/climate_normals/index_e.html)
- Environment Canada's Climate Data Online

  (available at http://climate.weatheroffice.gc.ca/climateData/canada_e.html)
- Environment Canada's Canadian Daily Climate Data (CDCD v1.02)

  (available at ftp://arcdm20.tor.ec.gc.ca/pub/dist/CDCD/)

The Corner Brook weather station (#8401300 at 48°57'00.000" N by 57°57'00.000" W) was used where available from the above noted data sources. Where data for the Corner Brook station were not available in the databases above, as was the case for certain climate parameters (i.e., ice storms and hurricanes), data for a nearby station or information in the literature based on a regional context was used. Any other data sources, when used, are documented in the climate parameter specific sections that follow.

3.6.3.2 Future

To date, the Province has collected four (4) datasets with a view to establishing a basis for the Province's approach to improving resilience to climate change impacts. These data sets are:

- Climate Projections for the Province

  Projected Impacts of Climate Change for the Province of Newfoundland & Labrador
  Dr. Joel Finnis, Department of Geography Memorial University of Newfoundland
  March 22, 2013

  This study down-scaled four internationally recognized global models to develop projections for the Province. The main projections for temperature and precipitation use regional data from twelve (12) weather stations in Newfoundland and six (6) stations in Labrador, ensuring that local conditions were included in the study.

- Flood risk mapping incorporating potential climate change influences

  Flooding is a natural process and the conditions that result in floods are often predictable and usually occur in the same areas, known as flood plains. Flooding and erosion processes are quite difficult to control and avoid. As such, the best and most cost effective method of minimizing their impact is proper management and planning of known flood plains. Flood plain management usually involves the adoption of land use regulations that limit human exposure to areas prone to flooding events. The Department of Environment and Conservation has undertaken hydro-technical studies, identifying and mapping regular and climate change flood risk zones and then implementing policies to limit future flood susceptible development in those areas. Climate change flood risk maps have been developed for seven (7) communities.

Two examples:

- *Flood Risk Mapping Project, Corner Brook Stream and Petrie's Brook*
  Government of Newfoundland and Labrador
  Water Resources Management Division
  Department of Environment and Conservation
  Prepared by AMEC Environment & Infrastructure, February 2013

- *Flood Risk Mapping Project, Goulds and Petty Harbour Area*
  Government of Newfoundland and Labrador
  Water Resources Management Division
  Department of Environment and Conservation
  Prepared by AMEC Environment & Infrastructure, March 2013

- Coastal Vulnerability Assessment (2011 – on-going)

  A Coastal Vulnerability Assessment program was established in 2011-12 to monitor the impact of coastal erosion in select sites. Data is now available for 104 sites around the Province, including 34 sites previously established by the Geological Survey of Canada and the Geological Survey of Newfoundland and Labrador.

  This dataset is comprised of the following:

  - *Coastal Monitoring in Newfoundland and Labrador: 2012 Update*
    M. Irvine, Geochemistry, Geophysics and Terrain Sciences, Memorial University
    Current Research (2013) Newfoundland and Labrador Department of Natural Resources, Geological Survey, Report 13-1, pages 43-54

  - *Coastal Monitoring in Newfoundland and Labrador*
    M.L. Irvine, Geochemistry, Geophysics and Terrain Sciences, Memorial University
    Current Research (2012) Newfoundland and Labrador Department of Natural Resources, Geological Survey, Report 12-1, pages 191-197

  - A Microsoft Excel™ spreadsheet (Coastalmonitoring_sites.xlsx[7]) identifying the monitoring sites.

  - Surveyed field data and associated GIS data layers.

- Predictions of Future Sea Level Rise (2010)

  Understanding the direction and magnitude of future sea-level change is important in planning and regulating development in coastal zones. Estimates of sea level rise change leading up to 2050 and 2100 are provided for four zones covering the Province in the following reference:

[7] Provided by the Province

- *Past and Future Sea Level Change in Newfoundland and Labrador: Guidelines for Policy and Planning*
  Martin Batterson, Geochemistry, Geophysics and Terrain Sciences, Memorial University and David Liverman, Geological Survey of Newfoundland and Labrador
  Current Research (2010) Newfoundland and Labrador Department of Natural Resources, Geological Survey, Report 10-1, page 129-141

This dataset was used to support definition of ocean water level boundary conditions for the two flood plain mapping studies previously noted.

Other readily available literature as documented in the specific climate parameter sections that follow was also reviewed.

3.6.4 Climate Variable Probability of Occurrence

The process of assessing the probability of a climate parameter's chance of occurrence was conducted by first identifying historical frequency. In some instances the relevant data were presented in a format that could be directly related to probability. In other instances a directly comparable format was either unintelligible or unattainable. A scoring system was used whereby a score between 0 and 7 was assigned to each parameter by subjectively relating the known or calculated frequency to one of the descriptive terms. Method A from Figure 3 of the Protocol, Probability Score Definitions, was adopted for use for this study. Figure 3, specific to Method A, is reproduced in part as Table 3-1 below.

Table 3-1: Risk Assessment Probability Score Definitions – Method A

(source: PIEVC, 2012)

PIEVC Probability Score	Method A	Range of Occurrences (per Year)
0	Negligible or not applicable	0
1	Improbable / highly unlikely	>0 to 0.05
2	Remote	>0.05 to 0.1
3	Occasional	>0.1 to 0.25
4	Moderate / possible	>0.25 to 0.75
5	Often	>0.75 to 1.25
6	Probable	>1.25 to 2
7	Certain / highly probable	>2

In many instances, though, the characterization of a climate parameter is descriptive rather than numeric. In these cases a definable means may be required to relate the available descriptive terms to that required for numeric probabilities. This process is outlined below and follows the same process used for a recent PIEVC based vulnerability assessment of flood control dams completed by the Toronto and Region Conservation Authority (TRCA, 2010).

The process is initiated with the question "what is the likelihood that an event will occur in a given year?" For example, a climate parameter having a historical annual frequency of 0.5 would be considered to mean that the climate event would occur, on average, once every two years. In consideration of the available descriptive terms, the term "moderate/possible" best represented the likelihood of its occurrence in a given year. In other words, it is by no means certain that it will occur every year.

Following the same rationale as above, parameters with known or calculated probability scores of greater than 2 were considered very likely to occur in a given year based simply on the historical record. Therefore, any probability scores greater than 2 were considered best represented by the term "certain/highly probable". Method A (ref. Table 3-1) relates the term "certain/highly probable" to a Probability Score of 7.

The above three rationales provide the relational benchmarks considered for this assessment. Consistency was maintained throughout the assessment process by using a suite of frequency ranges as described in Table 3-1 which related frequency ranges to PIEVC scores. Using this mechanism, where frequencies were available, the matching probability score was assigned.

3.6.4.1 High Temperature

Definition

The maximum temperature currently recorded for Corner Brook is 35°C, which occurred on June 27th of 2003 (Environment Canada, 2011b). As a reflection of the recorded high temperature, a threshold temperature of 30°C has been selected as representative of the measure of high temperatures for this report. This definition is consistent with other PIEVC protocols based climate change vulnerability assessments (e.g., TRCA, 2010; AMEC 2012).

Historical Climate

Climate normals for Corner Brook, obtained from Environment Canada Data Online (Environment Canada, 2011b) for the period from 1981 to 2010, indicate an average of 58.5 days a year with temperatures greater than 20°C and an average of 0.69 days per year had temperatures greater than 30°C.

The findings for 'number of days with a maximum temperature >30°C' outlined in Table 3-2 were compared with the established ranges in Table 3-1, resulting in a recommended probability scale of "remote" (or "2").

Trends

In a study by Zhang et al. (2000), trends in temperature change over Canada were analyzed during the 20th century. Over southern Canada, the mean annual temperature was found to have increased between 0.5 and 1.5°C (between 1900 and 1998), with the greatest warming found in the Prairie Provinces. It was found that the change was due largely to warmer overnight temperatures, meaning that the region was becoming less cold but not hotter. Specific temperature elements included in the analysis were the minimum, maximum, and mean temperature. For southern Canada, trends were computed for the period 1900-1998 and for the rest of Canada for the period 1950-1998.

Table 3-2: Summary of High Temperature Occurence (°C)

Description	Days/Year	
	Historic[1]	2050[2]
> 20°C	58.5	increasing
> 30°C	0.69	increasing
Probability Score	2 remote	3 occasional

Notes:
1. Source: Environment Canada, 2011b
2. Source: Finnis, 2013

The trend in increasing overnight temperatures was statistically significant over all of southern Canada. Easterling et al. (2000) discuss a similar finding in studies on the trends of temperatures in the United States over the period 1910-1998.

Climate Projections

Findings

As documented in the *Projected Impacts of Climate Change for the Province of Newfoundland & Labrador* report (Finnis, 2013) daily maximum temperatures are projected to increase throughout the Province. This report indicated the largest increase during the winter with temperatures increasing an average of 2.4°C with an ensemble uncertainty of 0.8. Finnis also estimated the projected increase in daily maximum temperature during the summer months (June, July, and August) to be 2.1°C, having an ensemble uncertainty of 0.4. It should be noted that Finnis' daily maximum temperatures are projected for 2038-2070. Furthermore Finnis' findings, similar to historic trends, show greater increases in overnight temperatures than daytime temperatures. The Finnis report does not provide data to compute projected daily occurrence of temperatures above 30°C.

Probability Scoring

Data for the average number of days having high temperatures in Newfoundland is not currently available in the Province's climate change datasets. As such, a quantitative estimate of the projected probability score for High Temperature can only be approximated from the available data.

Given that the findings of the Finnis report suggest an increase in daily maximum temperature it is inferred that the 'number of days with a maximum temperature >30°C' also has the potential to increase with climate change. As such, a probability score of '3' or 'occasional' has been assigned.

3.6.4.2 Low Temperature

Definition

The minimum temperature currently recorded for Corner Brook is -31.7°C, which occurred on January 22nd and 23rd as well as on February 10th, all in 1934 (Environment Canada, 2011b). As a reflection of this recorded low temperature, a threshold of -30°C was considered a representative and the threshold for low temperature for this assessment. This definition is consistent with other PIEVC protocols based climate change vulnerability assessments (e.g., TRCA, 2010; AMEC, 2012).

Historical Climate

Climate normals for Corner Brook, obtained from Environment Canada Data Online (Environment Canada 2011b) for the period from 1981 to 2010 indicate an average of 3.4 days per year with temperatures less than -20°C and an average of 0.04 days per year with temperatures less than -30°C (ref. Table 3-3).

Probability Scoring

The findings for 'number of days with a minimum temperature < -30°C' were compared with the established ranges in Table 3-4, resulting in a recommended probability score of "Improbable / highly unlikely" (or "1").

Climate Projections

Findings

Daily minimum temperatures are projected to increase approximately 3.5°C across Newfoundland over the period 2038-2070 (Finnis, 2013). The greatest increase would appear in Labrador (Finnis, 2010). Finnis reported that daily minimum temperatures during the winter months would increase by an average of 2.6°C with an average ensemble uncertainty of 0.8.

Probability Scoring

The upward movement in daily minimum temperatures into the future 2038-2070 time frame suggests the probability score of "Improbable / highly unlikely" (or "1") associated with the historic time frame will likely remain the same.

Table 3-3: Summary of Low Temperature Occurence (°C)

Description	Days/Year	
	Historic[1]	**2050[2]**
< -20°C	3.4	decreasing
< -30°C	0.04	decreasing
Probability Score	1 Improbable / highly unlikely	1 Improbable / highly unlikely

Notes:
1. Source: Environment Canada, 2011b
2. Source: Finnis, 2013

3.6.4.3 Heat Waves

Definition

A heat wave, as defined by Environment Canada, is considered to be a period where there are three or more consecutive days with a maximum temperature of 32°C or higher. This Environment Canada definition was also used for this report. It should be noted that in the *Projected Impacts of Climate Change for the Province of Newfoundland & Labrador* report Finnis defines a heat wave as a period of 6 days or longer having a maximum daily temperature of 5°C or more above normal.

Historical Climate

The initial screening of climate variables suggested a potential linkage between bridge design/functionality and heat waves. However, using the definitions described above and analysing data from Environment Canada it is concluded that heat waves have not occurred in Corner Brook historically whether using the Environment Canada or Finnis definitions.

Probability Scoring

No historical heat waves were identified, therefore a probability score of 'negligible' or '0' was assigned.

Climate Projections

Findings

Climate projections for the Province demonstrate increases in daily maximum temperature suggesting that heat waves may occur in the future.

Probability Scoring

A probability score of "Improbable / highly unlikely" reflects the projected upward trend in daily maximum temperatures into the future time frame as documented in the Finnis report.

Table 3-4: Summary of Heat Wave Occurence (# per year)

Definition	Days/Year	
	Historic[1]	2050[2]
Environment Canada	0	increasing
Finnis	0	increasing
Probability Score	0 Negligible	1 Improbable / highly unlikely

Notes:
1. Source: Environment Canada, 2011b
2. Source: Finnis, 2013

3.6.4.4 Frost (surrogate for Freeze/Thaw Cycles)

Definition

According to Environment Canada, frost is the circumstance when atmospheric temperatures close to the earth's surface fall to freezing or lower. Frost also describes the sublimation of water from the air into ice crystals onto objects/structures.

A freeze / thaw cycle is defined as having occurred when the maximum temperature is above 0°C and a minimum temperature below 0°C on the same day. For the purposes of this assessment, frost occurrence has been used as a surrogate for freeze / thaw cycles.

Historical Climate

Climate normals for Corner Brook, obtained from Environment Canada Data Online (Environment Canada 2011b) for the periods from 1981 to 2010 indicate an average of 146 frost free days per year (ref. Table 3-5). The average date of last spring frost is May 19th, while the average date of first fall frost is October 13th.

Probability Scoring

For this climate parameter, a probability score of '4' or 'Moderate / possible' was assigned to reflect that frost free days are typical in any given year and the probability score reflects the current expectation of occurrence as a means of establishing a trend into the future (ref. Table 3-6).

Climate Projections

Findings

Finnis found that the average number of frost days during the spring and autumn are expected to decrease substantially in Newfoundland, while Labrador experiences smaller changes in frost days. Corner Brook showed a potential increase of 29.8 frost free days per year for the 2038-2070 time frame having a total uncertainty of 7.1 days (Finnis, 2013).

Table 3-5: Summary of Frost Days for Corner Brook

Description	Historic[1]	Projected Lower bound[1]	Projected Upper bound[1]
DJF	81.8	77.2	80.4
MAM	48.5	33.1	36.9
JJA	0.2	0	0.2
SON	19.3	4.6	9.6

Notes:
1. Source: Finnis, 2010
2. December, January, and February (DJF); March, April, and May (MAM); June, July, and August (JJA); September, October, and November (SON)

As the number of frost days are projected to decrease in the future, it can be surmised that a decrease in days with freeze/thaw cycles is also a reasonable expectation in the long term. However, some locations have been shown to have increasing freeze/thaw cycles in the shorter future term versus reduced freeze/thaw occurrence in the longer future term as increasing daily temperatures (maximum and minimum) move through zero degrees as the daily average temperature.

Probability Scoring

The increase in the number of frost free days is surmised to also reflect a decrease in the number of days with a freeze/thaw cycle. As such, the recommended probability score associated with the frost events reflects the increasing trend in frost free days. Similarly, the probability score assigned to freeze/thaw cycles reflects the expected trend in this climate parameter.

Table 3-6: Summary of Frost Free Days and Freeze/Thaw Cycles (# per year)

Definition	Days/Year	
	Historic[1]	2050[2]
Frost Free Days	146	increasing
Probability Score	4 Moderate / possible	5 Often
Freeze/Thaw Cycles	n/a	decreasing
Probability Score	4 Moderate / possible	3 occasional

Notes:
1. Source: Environment Canada, 2011b
2. Source: Finnis, 2013

3.6.4.5 Mean Intensity of Precipitation Events (mm/day)

Definition

The mean intensity of a precipitation event is the measurement of the mean rate of precipitation occurring in a 24 hour period per rainfall event. To clarify, if the mean intensity of precipitation events increases fewer precipitation events could generate the same, or even increase, the mean daily precipitation.

Historical Climate

Daily precipitation data for Corner Brook was obtained from the *Projected Impacts of Climate Change for the Province of Newfoundland & Labrador* report. It can be seen (ref. Table 3-7) that the intensity of precipitation events in Corner Brook are historically well distributed, being slightly lower in the spring than in the other seasons. The largest recorded precipitation event for Corner Brook was 82.8mm which occurred in June of 1995 (Environment Canada, 2011b).

Probability Scoring

For this climate parameter, a probability score of ‘4’ or ‘Moderate / possible’ was assigned to reflect that mean intensity of a precipitation are typical in any given year and the probability score reflects the current expectation of occurrence as a means of establishing a trend into the future (ref. Table 3-8).

Climate Projections

Findings

As reported in the *Projected Impacts of Climate Change for the Province of Newfoundland & Labrador* report, the mean intensity of precipitation events is projected to increase throughout the Province. The Finnis report documented the largest increase on the island is projected during the winter months with mean intensity of precipitation events increasing an average of 0.6mm/day. Finnis also found that the projected change for Labrador was largest during the summer months (June, July, and August) being 0.4mm/day. It should be noted that Finnis’ mean intensity of precipitation events are projected for 2038-2070. For Corner Brook, the largest increase in the mean intensity of precipitation events occurs in the winter, with the smallest increase occurring in the summer months (ref. Table 3-7).

Probability Scoring

A probability score of ‘5’ or ‘often’ was assigned to reflect the increasing trend with regard to mean intensity of a precipitation.

Table 3-7: Summary of Mean Intensity of Precipitation Events for Corner Brook (mm/day)

Description	Historic[1]	Projected Lower bound[1]	Projected Upper bound[1]
DJF	7.9	8.2	8.8
MAM	6.9	7.1	7.3
JJA	7.9	8.1	8.7
SON	7.9	8.1	8.5

Notes:
1. Source: Finnis, 2010
2. December, January, and February (DJF); March, April, and May (MAM); June, July, and August (JJA); September, October, and November (SON)

Table 3-8: Summary of Mean Intensity of Precipitation Events

Definition	Days/Year	
	Historic[1]	2050[2]
Mean intensity of a precipitation event	7.9[3]	increasing
Probability Score	4 Moderate / possible	5 Often

Notes:
1. Source: Environment Canada, 2011b
2. Source: Finnis, 2013
3. Data for June, July, August

3.6.4.6 Maximum 5-Day Precipitation

Definition

Maximum 5-day precipitation is defined as the maximum total precipitation falling over a five day period. This includes all forms of precipitation such as rainfall, snowfall, sleet, etc.

Historical Climate

Banfield and Jacobs (1998) noted that precipitation in Newfoundland during the bulk of the year is associated with frontal cyclones and is influenced by their seasonal variability. Furthermore, precipitation due to convective processes is more likely to occur over more interior areas of Labrador and during the summer months. Precipitation due to convective processes is also likely to occur during the fall and early winter months near the coastline when cool continental air masses pass over the warmer open waters (Banfield and Jacobs, 1998).

Maximum 5-day precipitation data for Corner Brook was obtained from the *Projected Impacts of Climate Change for the Province of Newfoundland & Labrador* report. It can be seen that the magnitude of precipitation events in Corner Brook are historically well distributed, being slightly lower in the spring than in the other seasons (ref. Table 3-9).

Table 3-9: Summary of Maximum 5-Day Precipitation for Corner Brook (mm)

Description	Historic[1]	Projected Lower bound[2]	Projected Upper bound[2]
DJF	72.5	77	82.8
MAM	53.8	54.6	59.4
JJA	60.8	62.7	68.1
SON	69.1	70.6	76

Notes:
1. Source: Finnis, 2010
2. December, January, and February (DJF); March, April, and May (MAM); June, July, and August (JJA); September, October, and November (SON)

Probability Scoring

For this climate parameter, a probability score of '4' or 'Moderate / possible' was assigned to reflect that mean intensity of a precipitation are typical in any given year and the probability score reflects the current expectation of occurrence as a means of establishing a trend into the future (ref. Table 3-10).

Climate Projections

Findings

As reported in the *Projected Impacts of Climate Change for the Province of Newfoundland & Labrador* report by Dr. Joel Finnis the maximum 5-day precipitation for Corner Brook is projected to increase throughout the Province. This report showed the largest increase for Newfoundland being seen during the winter. Finnis also found that the projected change for Labrador was largest during the summer months. It should be noted that Finnis' mean intensity of precipitation events are projected for 2038-2070. For Corner Brook, the largest increase in the maximum 5-day precipitation occurs in the winter, with the smallest increase occurring in the spring months.

Probability Scoring

A probability score of '5' or 'often' was assigned to reflect the increasing trend with regard to mean intensity of a precipitation.

Table 3-10: Summary of Maximum 5-day Precipitation (mm)

Definition	Days/Year	
	Historic[1]	2050[2]
Maximum 5-day precipitation	60.8[3]	increasing
Probability Score	4 Moderate / possible	5 Often

Notes:
1. Source: Environment Canada, 2011b
2. Source: Finnis, 2013
3. Data for June, July, August

3.6.4.7 Extreme Precipitation Return Periods

Definition

An Intensity-Duration-Frequency (IDF) Curve is a tool that characterizes an area's rainfall pattern. By analyzing past rainfall events, statistics about rainfall reoccurrence can be determined for various standard return periods; for example, the depth and duration of the rainfall event that statistically occurs once every 10 years.

Historical Climate

A weather station with published IDF data is available specifically for the City of Corner Brook. IDF data is available, however, for weather stations at Stephenville Airport (#8403800 with a period of record from 1966 - 2007) to the south west of this study area and Deer Lake (#8401501 with a period of record from 1966 - 2002) to the north east. The current IDF reports/data available for these two stations is dated February 9, 2012.

A general review of the applicability of the data from these stations to support this assessment was completed for the 2013 hydrotechnical study of Corner Brook Stream (AMEC, 2013). The following comments stem from this review.

- The Deer Lake and Stephenville stations, relative to the Corner Brook Watershed, lie about 49 km and 65 km respectively from the approximate centroid of the watershed.

- Figure 3-2 illustrates the Public Forecast Warning Areas used by Environment Canada. The Public Forecast Warning Area boundaries were developed by Environment Canada several decades ago based on rigorous climate studies and considerable public consultation. The Corner Brook Stream Watershed lies almost entirely within the Deer Lake - Humber Valley Warning Area.

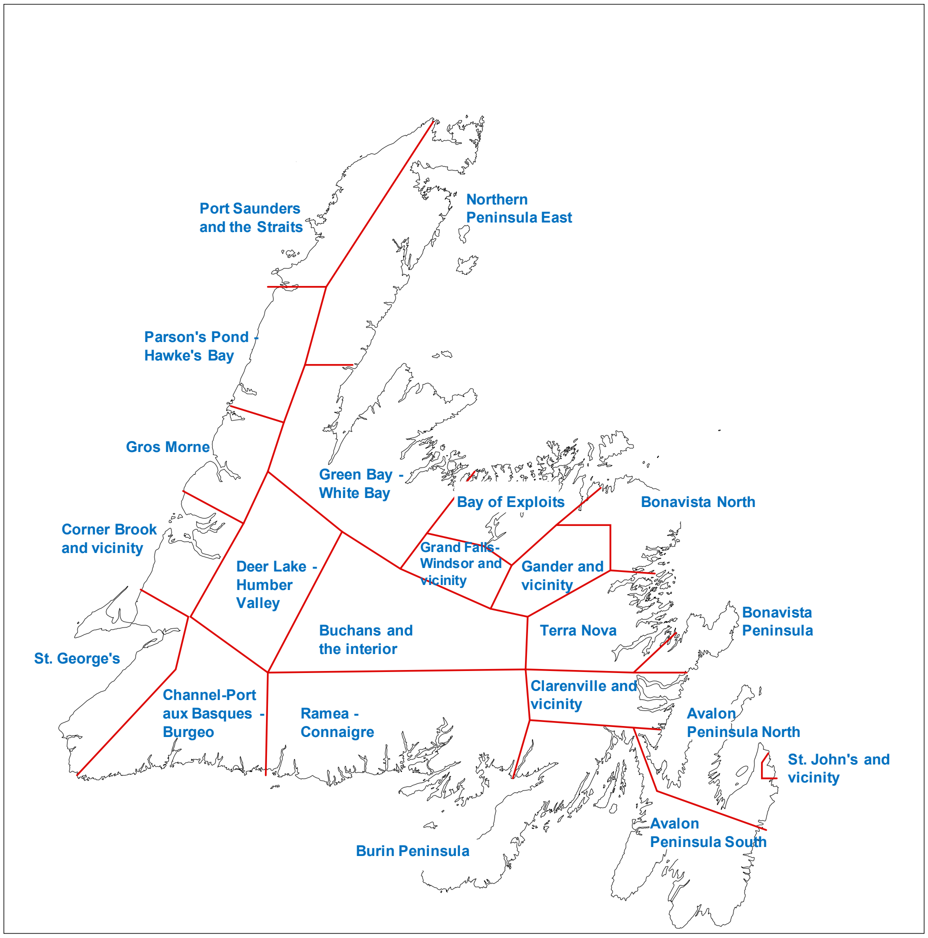


Figure 3-2: Public Weather Warning Regions for Newfoundland

(Based on http://www.weatheroffice.gc.ca/warnings/nl_e.html)

- Based on the information above, it is suggested that the Deer Lake IDF data is representative for the drainage basin feeding Corner Brook Stream.

The 1:20 year precipitation amounts were estimated by interpolation (using the Power function trending option in Microsoft Excel™) from the 1:10 year and 1:25 year amounts. The IDF estimates for the project area are provided in Table 3-11.

The historical extreme precipitation return periods are provided below in Table 3-12. Historical extreme precipitation return period data for Corner Brook was obtained from the *Projected Impacts of Climate Change for the Province of Newfoundland & Labrador* report. These data were accrued and analysed by Dr. Finnis from the Adjusted & Homogenized Canadian Climate Data using the same methods used by Environment Canada for their IDF curves.

Probability Scoring

For this climate parameter, a probability score of '4' or 'Moderate / possible' was assigned to reflect that return period precipitation values are typical in any given year and the probability score reflects the current expectation of occurrence as a means of establishing a trend into the future (ref. Table 3-13).

Table 3-11: Return Period Rainfall Amounts for Deer Lake (mm)

Duration	Frequency		
	20 yr	50 yr	100 yr
10 min	10.7	13.2	14.7
30 min	15.9	18.7	20.5
1 h	20.7	24.1	26.2
2 h	30.6	36.3	39.7
6 h	44.0	50.5	54.6
12 h	53.6	61.2	65.9
24 h	62.2	65.3	76.4

Table 3-12: Summary of AHCCD-Derived Results for Extreme Precipitation Return Periods for Deer Lake (24 hour duration)

Description	Historic[1]	Projected Mean[1]	Projected Max[1]
20yr	63.5	69.9	72.3
50yr	70.9	77.9	81.1
100yr	76.4	83.9	87.7

Notes:
1. Source: Finnis, 2010

Climate Projections

Findings

As reported in the *Projected Impacts of Climate Change for the Province of Newfoundland & Labrador* report, precipitation levels for extreme precipitation return periods for the Corner Brook area are projected to increase. The greatest increase in the projected precipitation levels for Corner Brook is noted for the 100 year event, an increase of 14.7mm.

Probability Scoring

A probability score of '6' or 'Probable' was assigned to reflect the significance of the increases in projected return period rainfall amounts (ref. Table 3-13).

Table 3-13: Summary of Probability Scoring for Return Period Rainfall (mm)

Definition	Days/Year	
	Historic[1]	2050[2]
Return Period Rainfall – 100 Year 24 Hour Duration	76.4	83.0 (mean) 87.7 (maximum)
Probability Score	4 Moderate / possible	6 Probable

Notes:
1. Source: Environment Canada, 2011b
2. Source: Finnis, 2013

Flooding

As previously noted, a hydrotechnical study of Corner Brook Stream was completed in 2013. Flood plain maps were prepared for existing conditions and future conditions for the periods 2020, 2050 and 2080. As the current approved climate projections for the Province target the 2050 period and current flood plain mapping requirements for the Province also target the 2050 period, this review of flooding related to the Main Street Bridge will focus only on the 2050 future period.

Further, the approved climate projections for the Province were not available to the 2013 hydrotechnical study. As such, the following rainfall estimates were used for the hydrotechnical study:

The Finnis (2013) projected rainfall data was defined for Stephenville only. Nonetheless, the projected estimates for Stephenville were applied, unchanged, to the Corner Brook Stream watershed model. The flood plain maps for 2050 represent the maximum inundation limits for all of the scenarios evaluated and as such, the flooding resulting from the Finnis 2050 projections are reflected on the Corner Brook Stream flood plain maps (ref. Figures 3-3 and 3-4).

Table 3-14: 100 Year Rainfall Totals used for the 2013 Corner Brook Hydrotechnical Study

Description	Duration	Rainfall (mm)
AMEC 2050 Maximum	12 hour	73.2
Finnis 2050 Maximum	12 hour	101.6
AMEC 2050 Maximum	24 hour	84.0
Finnis 2050 Maximum	24 hour	135.2

As noted previously, Main Street is presently designated as a collector road. As such, and for compliance with the Return Period Policy of the Province, the obvert of the bridge opening or top of pier should be set to an elevation at or above the 50 year flood water level. The bridge top of deck was surveyed in 2011 as having an elevation of 3.32 m (the minimum obvert elevation was 2.3m). The current flood plain mapping illustrates existing conditions flooding at an elevation of 4.11 m and 4.27 m for the 20 year and 100 year floods, respectively. Similarly, the 2050 flood mapping illustrates elevations of 4.61 and 4.92 m, respectively, for the 20 year and 100 year floods. Using the AMEC 2050 Maximum rainfall, which aligns with the Finnis (2013) projections for rainfall in Corner Brook, the 20 year and 100 year flood elevations at the bridge are 4.21m and 4.35m, respectively; lower than the Finnis estimates but still overtopping the bridge deck.

With regard to probability scoring, a score of ‘4’ or ‘Moderate / possible’ was assigned to reflect the current expectation of occurrence as a means of establishing a trend into the future. A probability score of ‘5’ or ‘often’ was assigned to 2050 to reflect the increasing trend with regard to expectation of flooding.

3.6.4.8 Sea Level Rise

Starting water levels for the hydraulic modelling supporting the hydrotechnical assessment for Corner Brook (AMEC, 2013) incorporated sea level rise estimates for future periods as follows outlined in Table 3-15.

Table 3-15: Sea Level Rise Estimates for Future Periods at Corner Brook

Period	Sea Level Rise Estimate
2020	0.05 m
2050	0.23 m
2080	0.56 m

These estimates were abstracted from Table 3 and Figure 4 in Batterson and Liverman (2010) using Zone 2 information to reflect conditions at Corner Brook. This document is presently the approved reference for sea level rise estimates in the Province.

The bed elevation of Corner Brook Stream at the Main Street Bridge is in the range of 0.83 m to 1.21 m.

The Mean Water Level (MWL) represents the height above chart datum of the mean of all hourly water level observations used for the tidal analysis and that particular, or, the average of all hourly water levels over the available period of record. The MWL at Corner Brook is 1.2 m suggesting that lowering the stream bed as a mitigative measure to reduce flood levels in this reach would not be a preferred option.

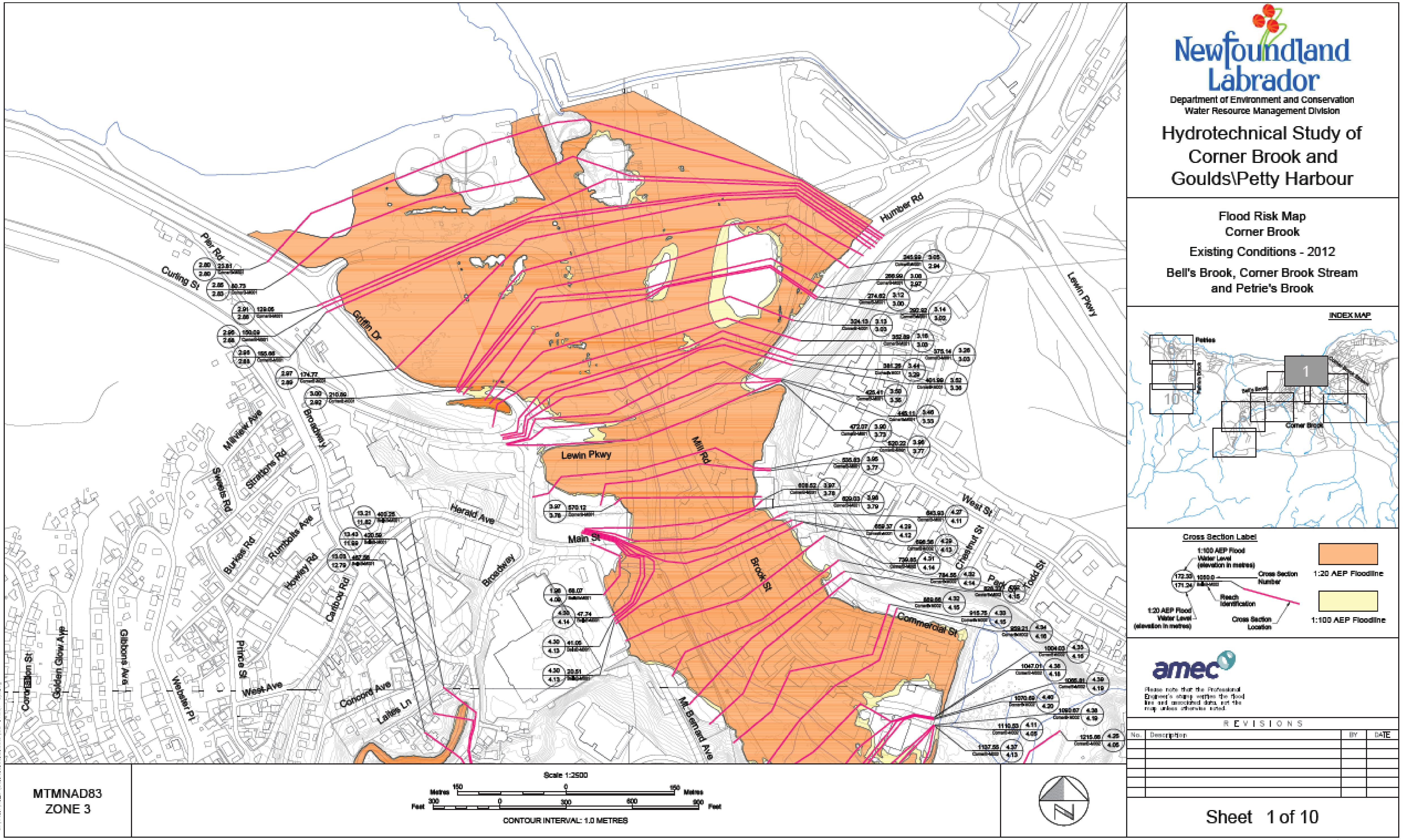


Figure 3-3: Corner Brook Flood Plain Map - Existing Conditions

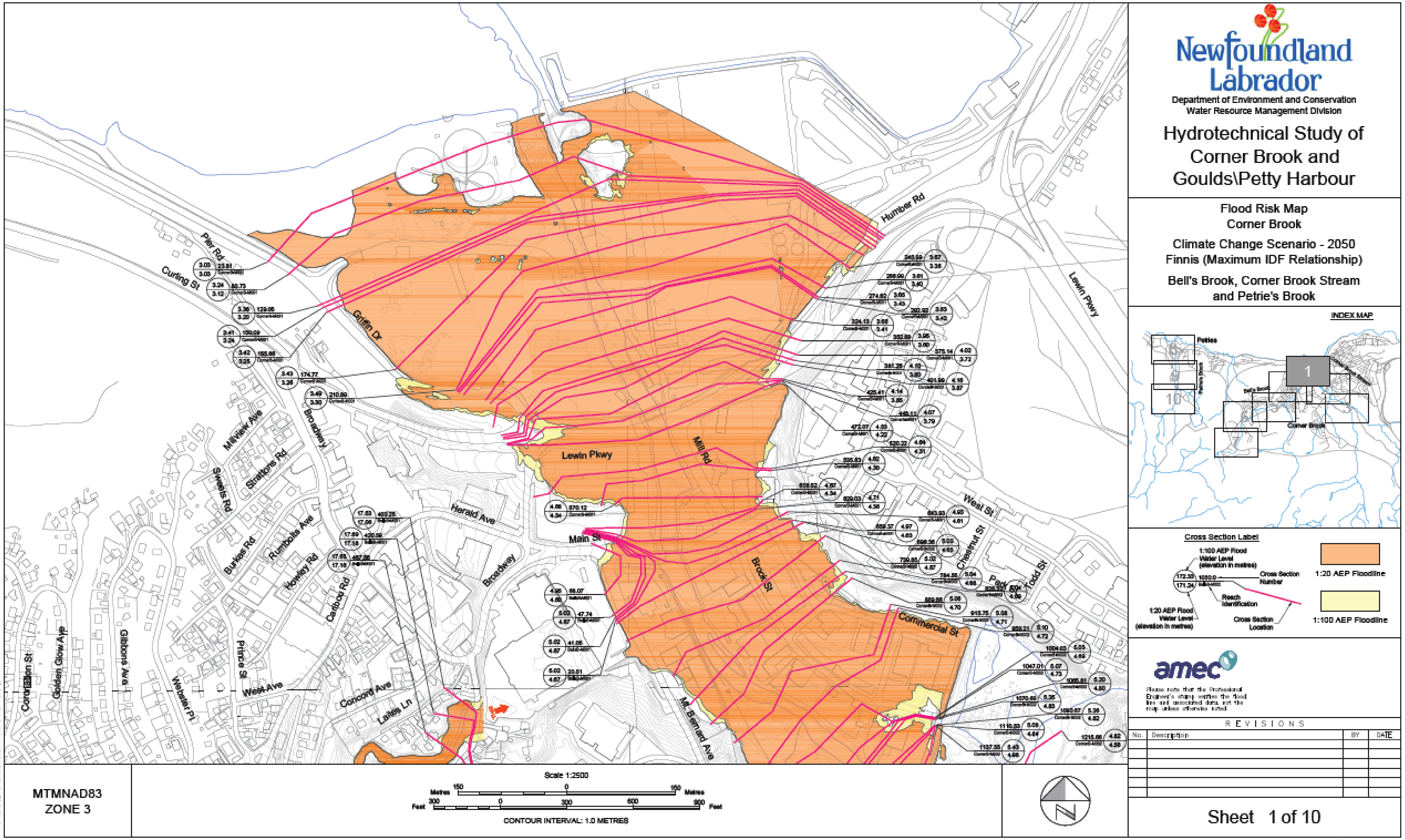


Figure 3-4: Corner Brook Flood Plain Map - 2050 Conditions

With regard to probability scoring, a score of ‘4’ or ‘Moderate / possible’ was assigned to reflect the current expectation of occurrence as a means of establishing a trend into the future. A probability score of ‘5’ or ‘often’ was assigned to 2050 to reflect the increasing trend with regard to expectation of flooding.

3.6.4.9 Climate Parameters Summary

A summary of the historical and future climate parameter probability scores is provided in Table 3-16. The selected probabilities associated with a substantial number of parameters are increasing from the historic period into the future. Genearlly, winter related parameters have been identified with decreased probability moving into the future, primarily related to the anticipation of rising temperature. Of particular interest are increases in the rain related parameters which could have a direct impact on performance of the subject infrastructure.

Table 3-16: Climate Parameters Summary

Climate Parameter	Anticipated Changes	
	Historic	Future 2050
Increasing		
Heat Waves	0	1
High Temperature	2	3
Frost Free Days	4	5
Mean Intensity of Precipitation	4	5
Sea Level Rise	4	5
Maximum 5-day Precipitation	4	5
Flooding	4	5
Extreme Precipitation	4	6
Decreasing		
Freeze Thaw Cycles	4	3
Unchanged		
Low Temperature	1	1

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SECTION 4

PIEVC PROTOCOL STEP 3

RISK ASSESSMENT

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4 STEP 3 - RISK ASSESSMENT

4.1 OVERVIEW

An engineering vulnerability exists when the total load effects on infrastructure exceed the total capacity to withstand them, while meeting the desired performance criteria. Where the total loads or effects do not exceed the total capacity, adaptive capacity exists.

Step 3 of the PIEVC Protocol involves the identification of infrastructure components which are likely to be sensitive to changes in specific climate parameters (ref. Section 3). This step focuses on qualitative assessments as a means of prioritizing more detailed Evaluation Assessments or Engineering Analyses, if required, in Step 4 of the Protocol. In other words, professional judgment and experience are used to determine the likely effect of individual climate events on individual components of the infrastructure. To achieve this objective, the Protocol uses an assessment matrix process to assign an estimated probability and an estimated severity to each potential interaction.

As noted in Section 3.6.4, the Protocol specifies that a scaling system with values ranging from 0 to 7 be applied to rank both the potential climate events and the estimated response severity. For this project, Method A (climate probability scores) and Method E (response severity scores) have been selected as being the most appropriate based on the available data. The climate probability scores identified for use in the risk assessment are documented in Section 3.6.4 of this report.

An evaluation of this type is usually completed during a Risk Assessment Workshop which brings together representatives of the infrastructure owner/operator plus other stakeholders.

The objectives of a risk assessment workshop would include:

- learning more about interactions between infrastructure components and weather events;
- identifying anecdotal evidence of infrastructure responses to weather events;
- discussing other factors that may affect infrastructure capacity;
- identifying actions that could address climate effects,
- Identifying and documenting the local perspective relevant to the subject infrastructure.

Given the nature of this climate change vulnerability assessment (ref. Section 1.2), AMEC completed the risk assessment of the Main Street Bridge independently.

4.2 RISK ASSESSMENT RESULTS

4.2.1 Methodology

The complete Risk Assessment Matrix for this project is included in Figure 4-1 of this report. Under each *climate effect* column heading, there are four sub-headings, as follows:

1. **Y/N (Yes/No).** This field is marked "Y" if there is an expected interaction between the infrastructure component and the climate effect, and "N" if not. This was triggered by reviewing potential *performance responses* in light of the climate variable. For example, would or could any of the following issues be affected by the anticipated changes in a climate variable:

   - Structural Design (Design)
     - Safety
       - Load carrying capacity
       - Overturning
       - Sliding
       - Fracture
       - Fatigue
       - Serviceability
     - Deflection
       - Permanent deformation
       - Cracking and deterioration
       - Vibration
     - Foundation Design Considerations
   - Infrastructure Functionality (Functionality)
     - Level of Effective Capacity (short, medium, long-term)
     - Equipment (component selection, design, process and capacity considerations)
   - Infrastructure Performance (Performance)
     - Level of Service, Serviceability, Reliability
     - Materials performance
   - Watershed, Surface Water and Groundwater (Environment)
     - Erosion along watercourses
     - Erosion scour of associated/supporting earthworks
     - Sediment transport and sedimentation
     - Channel re-alignment / meandering
     - Change in water quantity
     - Change in water quality (Water Quality)
     - Change in water resources demands
     - Change in groundwater recharge
     - Change in thermal characteristics of water resource
   - Operations and/or Maintenance
     - Structural aspects
     - Equipment aspects

  - Functionality and effective capacity
- Emergency Response (Emergencies)
  - Storm, flood, ice, water damage
- Insurance Considerations (Insurance)
- Municipal Considerations (Policies)
  - Codes
  - Public sector policy
  - Land use planning
  - Guidelines
  - Inter-government communications
- Social Effects (Social Effects)
- Economic considerations (Economic)

A general 'Other' category was also included to allow capture of issues not covered by the aforementioned considerations.

2. **P (Climate Probability Score Factor).** This value reflects the expectation of a change in a climate variable under the influence of climate change as outlined in Section 3.6.4.

3. **S (Response Severity Score Factor).** This value reflects the expected severity of the interaction between the climate phenomena and the infrastructure component. As such, different climate phenomena may lead to varying response severities.

4. **R (Priority of Climate Effect).** This is calculated as P multiplied by S. This priority value is used to determine how the interaction will be assessed in the next steps of the protocol. Since this is a qualitative assessment, the R should not be used to prioritize recommended actions.

At the end of this assessment, three categories of infrastructure-climate interactions emerge:

1. **R > 36.** "High" possibility of a severe effect. Interactions in this range should lead to recommendations in Step 5 of the Protocol.

2. **12 < R ≤ 36.** "Medium" possibility of a major effect. These effects are considered to be in a "grey area", where it is uncertain whether the impact is sufficient to cause the need for recommendations. Step 4 of the protocol, which involves a quantitative analysis, can be used to determine which effects to leave aside and which to discuss further.

3. **R ≤ 12.** "Low" possibility of an effect. These infrastructure-climate interactions are typically left aside without further analysis or recommendations.

A summary of the results of the risk assessment are provided in Figure 4-1, at the end of this section. The colour coding in the Figure relates to the Priority of Climate Effect ranges (i.e., “high” (red), “medium” (yellow) and “low” (green)).

A major outcome of the risk assessment workshop was that only a few infrastructure-climate interactions were identified in the “High” category. The highest Priority of Climate Effect value was calculated as 36 with a number of infrastructure interactions with precipitation type climate parameters.

4.2.2 Results

This section provides some insight to the matrix values resulting from the Risk Assessment documented in Table 4-1.

a) Main Street Bridge

As expected, the highest severity ratings are linked to performance responses that contribute to risks to public safety (namely, flooding). The climate parameters triggering these responses were all related to increased expectation of more severe precipitation which, by extension, is linked to potential flooding of Corner Brook Stream.

Scour around bridge pier foundations is also associated with flooding. Bridge failure due to scour has been a common reason for bridge failures[8]. It is easy to conceive that potential for scour could be directly impacted changing hydrology of Corner Brook Stream, leading to more debris flow around piers and perhaps increased duration of erosive velocities of streamflow. The piers of the Main Street Bridge have not generally exhibited signs of scour, however upstream stream inverts are lower than downstream stream inverts suggesting erosion is occurring at the bridge. It is recommended that scour at the bridge be periodically monitored.

Freeze/thaw cycles may persist into the near future at similar or increased rates and are then expected to subside in frequency into the far future with rising temperatures. It has been anticipated in this assessment that current procedures effectively deal with these circumstances that these procedures will also effectively manage the effects of freeze thaw (cracks or strain on the wearing material due to additional expansion and contraction cycles). However, it is recommended that near term changes in the expected frequency of freeze/thaw cycles be evaluated to determine the effects of potential increased cycles on bridge wearing surfaces.

Generally codes and guidelines used for a current bridge design are based on climate data are quite dated. Some may be as old as 50 or 60 years. As it is clear that the climate is changing, and will continue to change, it is recommended that the data referenced in the applicable design

[8] http://www.fisherassoc.com/articles/149/Bridge_Scour_The_1_reason_for_bridge_failures

codes and guidelines be updated to reflect current information. An alternate approach, completing a site-specific climate assessment to determine whether in-depth analysis is necessary for the infrastructure being designed or evaluated may be prudent.

b) Administration

No specific information regarding administration of the Main Street Bridge was available for this assessment. As such, a generic review of potential issues founded on previous experience was completed.

The primary performance responses considered in regard to Personnel were related to their ability to complete normal (and emergency) operations and maintenance activities specific to the Main Street Bridge. Climate parameters included in this assessment impacting these activities included all manner of increased rain. Additional climate parameters not specifically included in this assessment which may also hamper operations and maintenance activities are Freezing Rain, Ice Storm, Snow Accumulation, Winter Rain, Lightning, Hail Storm, and High Winds. In general, the noted climate conditions all could contribute to impaired movement of crews and associated resources and equipment.

High Temperature and Heat Waves were noted due to potential impacts on crews to maintain a normal operations and maintenance schedule. Current Occupational Health and Safety requirements have protocols for working outdoors in hot weather. This includes availability of fluids, rest/cooling stations, duration of exposure, etc. Increases in occurrence of high temperature days and heat waves may change the nature of working in hot weather perhaps resulting in shorter work days, longer rest/cooling periods, etc. Ultimately, additional staff may be required for a “normal” crew to affect the same operations/maintenance efforts.

‘Record Keeping’ is an aspect of normal operations that has been demonstrated through other climate change risk assessments to be a very important component of overall asset management. Particularly in a time a potential change, record keeping provides the basis to maintain information about the subject infrastructure (maintenance activities, repairs, other issues, etc.) and also to record climatic events that impacted the infrastructure (flooding, ice floes, etc.). The recording of climatic events specific to the subject infrastructure also provides a basis for change detection and determination of trends. The climate data and trends can then be used to update the risk assessment and/or adaptively manage the change.

c) Transportation

The assessment of the transportation function of the bridge was assessed.

Ice accretion, linked to lower temperatures, has a high probability of affecting the surface (i.e., black ice) and that the impact of having ice on the deck is a traffic hazard. However, with the general expectation of rising temperatures, existing procedures for ice mitigation are expected to be adequate.

d) Communications

Communication systems necessary to maintain operation and maintenance activities of the Main Street Bridge were not considered to be serious risk from any of the climate phenomena evaluated for this risk assessment.

4.3 DATA SUFFICIENCY

The Risk Assessment step of the evaluation required judgments on significance, likelihood, response and uncertainty in the context of the probability of climate effects and the severity of infrastructure responses to the effects. Some judgments could be fairly easily made based on available information, however, others required use of “indirect” information. This complicated the assessment of the response severity of climate effects on infrastructure operations, and, more specifically, introduced additional uncertainty into the assessment.

In general, the data available were sufficient for the non-numerical (qualitative), engineering judgment-based screening purposes of this risk assessment.

It is again noted that this scoped climate change vulnerability assessment reviewed climate change and infrastructure datasets as applicable to the PIEVC Protocol; specifically Steps 1 and 2, and a preliminary, independent application of Step 3 of the Protocol only.

Performance Response (✓ if yes)

Infrastructure Component	Structural Design	Functionality	Watershed, Surface Water and Groundwater	Operations, Maintenance, Materials Performance	Emergency Response	Insurance Considerations	Policy Considerations	Social Effects	Water Quality	Economic Considerations	*Other*
Operations and Maintenance											
Personnel				Y	Y	Y	Y			Y	
Transportation		Y		Y	Y	Y			Y		
Communications	Y	Y		Y	Y						
Main Street Bridge											
Foundation	Y	Y		Y				Y		Y	
Support Pier	Y	Y	Y	Y			Y	Y		Y	
Abutments	Y	Y	Y	Y			Y	Y		Y	
Deck	Y	Y	Y	Y	Y	Y	Y	Y		Y	
Drainage System	Y	Y	Y	Y		Y	Y	Y		Y	

Climate Events

Infrastructure Component	High Temperature (2 to 3)				Low Temperature (1 to 1)				Heat Waves (0 to 1)			
	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R
		3				1				1		
Operations and Maintenance												
Personnel	Y	3	4	12	N				Y	1	4	4
Transportation	N				N				N			
Communications	N				N				N			
Main Street Bridge												
Foundation	N				Y	1	2	2	N			
Support Pier	N				Y	1	3	3	N			
Abutments	N				Y	1	3	3	N			
Deck	Y	3	5	15	Y	1	3	3	Y	1	6	6
Drainage System	N				Y	1	5	5	N			

Infrastructure Component	Frost Free Days (4 to 5)				Freeze Thaw Cycles (4 to 3)				Sea Level (4 to 5)			
	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R
		5				3				5		
Operations and Maintenance												
Personnel	N				N				N			
Transportation	N				Y	3	4	12	N			
Communications	N				Y	3	2	6	N			
Main Street Bridge												
Foundation	N				N				N			
Support Pier	N				Y	3	3	9	N			
Abutments	N				Y	3	3	9	N			
Deck	N				Y	3	6	18	Y	5	7	35
Drainage System	N				Y	3	6	18	Y	5	3	15

Infrastructure Component	Mean Intensity of precipitation Events (4 to 5)				Extreme Precipitation Return Periods (4 to 6)				Maximum 5-day Precipitation (4 to 5)			
	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R
		5				6				5		
Operations and Maintenance												
Personnel	Y	5	5	25	Y	6	5	30	Y	5	5	25
Transportation	Y	5	4	20	Y	6	5	30	Y	5	5	25
Communications	Y	5	4	20	Y	6	4	24	Y	5	5	25
Main Street Bridge												
Foundation	Y	5	6	30	Y	6	6	36	Y	5	6	30
Support Pier	Y	5	6	30	Y	6	6	36	Y	5	6	30
Abutments	Y	5	3	15	Y	6	3	18	Y	5	3	15
Deck	Y	5	7	35	Y	6	7	42	Y	5	7	35
Drainage System	Y	5	4	20	Y	6	4	24	Y	5	4	20

The highlighted values depicted in this Figure are the 'Priority of Climate Effect' or 'R' values resulting from the Risk Assessment.

Priority of Climate Effect		
R > 36	High	(red)
12 < R ≤ 36	Medium	(yellow)
R ≤ 12	Low	(green)

Figure 4-1: Risk Assessment Results

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SECTION 5

PIEVC PROTOCOL STEP 4

ENGINEERING ANALYSIS

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5 STEP 4 - ENGINEERING ANALYSIS

Step 4 of the PIEVC Protocol focuses on the determination of adaptive capacity. Specifically, if the climate changes as described in Step 2, does the infrastructure of interest have adaptive capacity available to meet the desired performance criteria? If the adaptive capacity is determined not to exist, this evaluation determines the additional capacity required to meet the desired performance criteria, again if the climate changes as described in Step 2.

The engineering analysis step requires the assessment of the various factors that affect load and capacity of the subject infrastructure. Based on this assessment, indicators or factors are determined in order to relatively rank the potential vulnerability of the infrastructure elements to various climate effects.

As noted in the Protocol, much of the data required for Engineering Analysis may not exist, or may be very difficult to acquire, and this analysis requires the application of multi-disciplinary professional judgment. Thus, even though numerical analysis is applied, the practitioner is cautioned to avoid the perception that the analysis is definitively quantitative or based on measured parameters. The results of the analysis yield a set of parameters that can be ranked relative to each other, based on the professional judgment of the practitioner. The results can also be used to rank the relative vulnerability or resiliency of the infrastructure.

A PIEVC Protocol based engineering analysis is driven by the following steps:

1. Determine the existing load on the subject infrastructure
2. Determine the anticipated climate change load
3. Determine other change loads
4. Determine the total load
5. Determine the existing capacity
6. Calculate the projected change in existing capacity arising from aging/use of the infrastructure
7. Determine additional capacity
8. Determine the project total capacity
9. Determine the vulnerability ratio
10. Determine the capacity deficit

The mechanism by which each of these loads and capacities are computed is outlined in detail in the PIEVC Protocol.

Given the scoped approach for this climate change vulnerability assessment, this step of the Protocol was not completed for this case study.

However, an approach for engineering analysis which could be completed would be a review of the design issues associated with infrastructure based on computations using the projected extreme rainfall values. This could take two forms, namely:

1. Assessment of the performance of the infrastructure given the current design but under future rainfall, and,
2. Assessment of the changes (if any) needed in the design of the infrastructure to reflect future rainfall as the design basis.

SECTION 6

PIEVC PROTOCOL STEP 5

CONCLUSIONS AND RECOMMENDATIONS

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6 STEP 5 - CONCLUSIONS AND RECOMMENDATIONS

6.1 LIMITATIONS

The uncertainty in the assessment of the likelihood and magnitude of climate - infrastructure interactions is a limitation of this study. As outlined in Step 3, judgment of likelihood and magnitude were unique to the individuals who took part in the risk assessment. The probability and risk values documented from the risk assessment are consensus views of likelihood and magnitude and the range of opinions contributes to uncertainty.

Overall, the results of this study are based on applying professional judgment to the assessment of the most current information available within the scope of the PIEVC protocol and can, therefore, be used as a guide for future action on the part of the City of Corner Brook.

6.2 OVERVIEW

Where vulnerability is identified, options to negate vulnerability have been assessed including reductions in load effects, changes in the performance criteria or additional capacity building. As a general rule, systems with high adaptive capacity are better able to deal with climate change impacts. Step 5 details infrastructure-specific recommendations on adaptive measures, such that the desired performance criteria are met in those circumstances where Steps 3 has indicated insufficient adaptive capacity.

As noted previously, this scoped risk assessment was limited to the application of Steps 1 and 2 of the PIEVC Protocol and a preliminary, independent application, by AMEC, of Step 3 of the Protocol.

The recommendation categories, based on the PIEVC protocol, are as follows:

- *Remedial engineering or operations action required*
- *Management action required*
- *Additional study or data required*
- *No further action required.*

The climate factors identified as potentially contributing to infrastructure vulnerability will be evidenced as gradual changes. However, often the extremes (such as extreme rainfall), even if uncommon, have a far greater impact on public perception of risk. Under climate change scenarios, some of these phenomena are anticipated to occur more frequently.

In fact, the greatest pressure to initiate adaptive action comes not from climate change but from timing of planned infrastructure improvements such as the Main Street Bridge replacement or major repairs. So while perceived changes in the future climate effects may have revealed infrastructure vulnerabilities, the City of Corner Brook is in an ideal position to proactively mitigate and adapt to these challenges through existing programs.

6.2.1 Main Street Bridge

The vulnerabilities judged to be of the highest priority for the bridge are those associated with performance responses that contribute risks to public health and safety (namely, flood related). Specifically, increased rainfall and the associated increase in streamflow in Corner Brook Stream were identified as triggers for these vulnerabilities.

A number of lower-ranked interactions and considerations associated with the bridge were also identified, as outlined below:

- increased potential for erosion/scour of the bridge pier due to changing/increasing precipitation
- potential for near term increase in freeze/thaw cycles leading to additional cracking or strain on the wearing material although a longer term decrease in days with freeze/thaw cycles is anticipated
- rising temperatures was not considered to impact the bridge asset but may impact operations and maintenance efforts and/or procedures
- good record keeping was noted as important for change detection and development of adaptive management approaches

6.3 RECOMMENDATIONS

Recommendations stemming from the application of the PIEVC Protocol to the Main Street Bridge in the City of Corner Brook to assess risks and vulnerabilities to projected changes in climate phenomenon in the future are outlined below.

- It is recommended that near term changes in the expected frequency of freeze/thaw cycles be evaluated to determine the effects of potential increased cycles on bridge wearing surfaces.
- It is recommended that scour at the bridge be periodically monitored.
- It is recommended that the data referenced in the applicable design codes and guidelines be updated to reflect current information. Alternatively, a mechanism to require completion of a site-specific climate assessment to determine whether in-depth analysis is necessary for infrastructure being designed or evaluated be developed.
- It is recommended that recording of climatic events specific to the subject infrastructure be a regular procedure in the administration of the infrastructure.

- It is recommended that the climate change projections available from the Province be augmented such that the time series upon which the projections area based are made available such that more in-depth interrogation of the datasets is possible.
- It is recommended that this scoped climate change vulnerability assessment be completed in full for all components of the PIEVC protocol.[9]

General recommendations regarding climate change risk assessment of infrastructure stemming from the workshops included:

- The Province should develop procedures and/or policies for incorporating risk assessment into infrastructure planning and development practices.
- The development of climate change datasets by the Province is a great step forward in breaking down perceived barriers to climate change risk assessments. However, barriers that still exist as a consequence of the lack of coordination among departments and lack of understanding of the “do nothing” scenario still need to be addressed. As such, better Government interdepartmental coordination should be advanced towards a consistent view of the requirements for incorporating risk assessment into infrastructure planning and development practices.
- The workshops clearly demonstrated value in advancing understanding of climate change issues affecting infrastructure in the Province. Further opportunities for training/education about climate change and the potential impacts to the Province should be continued for all levels of government and the private sector.
- The climate change datasets developed by the Province can generally support climate change risk assessment. However, the Province should not view these datasets as static. Examples of gaps in the datasets have already been noted (i.e., short duration IDF data). With changing science and data collection new projections are being developed around the world. The Province should develop a review cycle for its datasets. Further, the Province should also allow for new datasets to be analysed and incorporated into the larger suite of datasets.

[9] Adoption of this recommendation would encompass some of the other recommendations itemized in the list.

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SECTION 6

REFERENCES

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7 REFERENCES

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APPENDICES

APPENDIX A - Project Documentation

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APPENDIX A

Project Documentation

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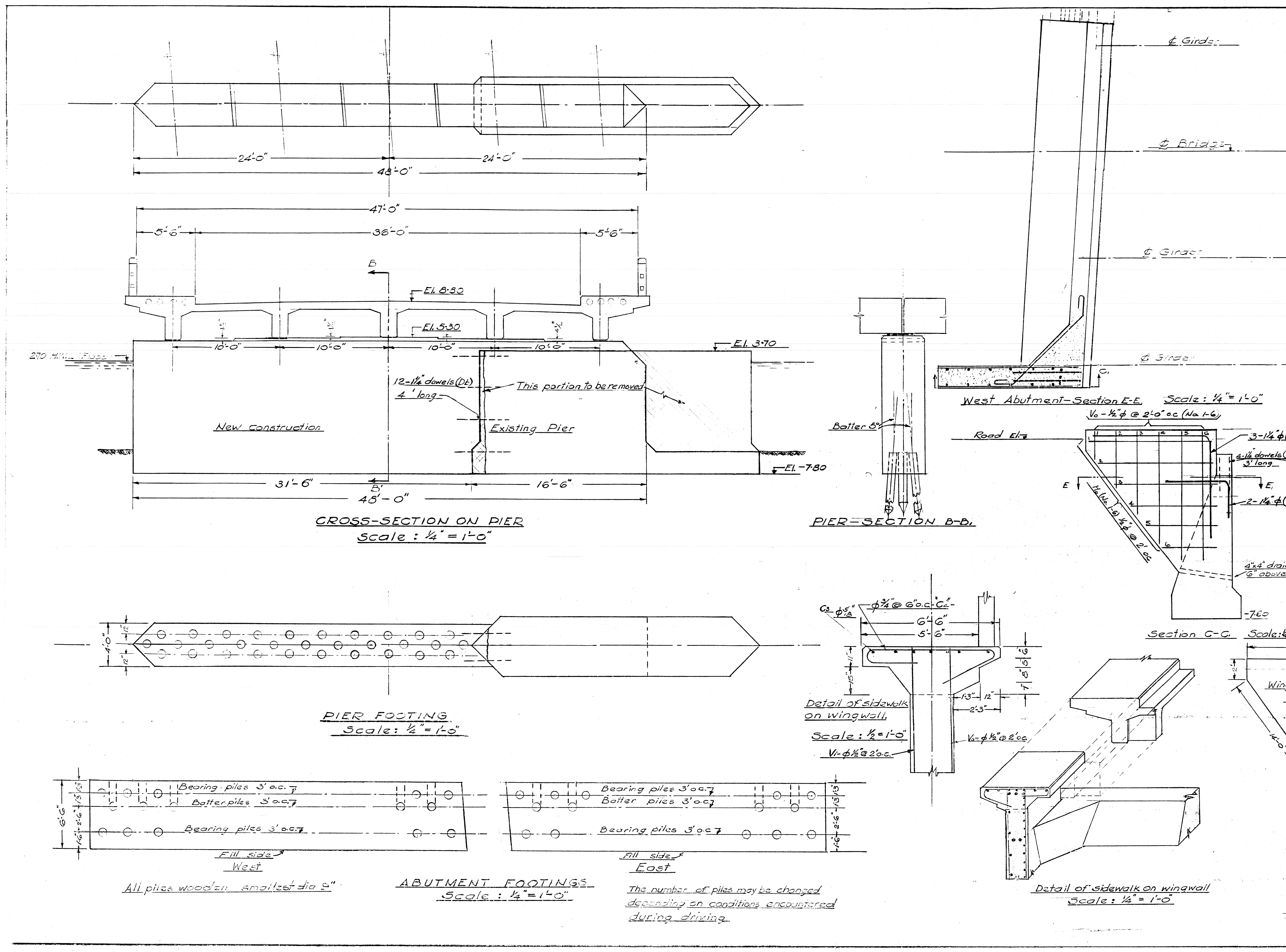
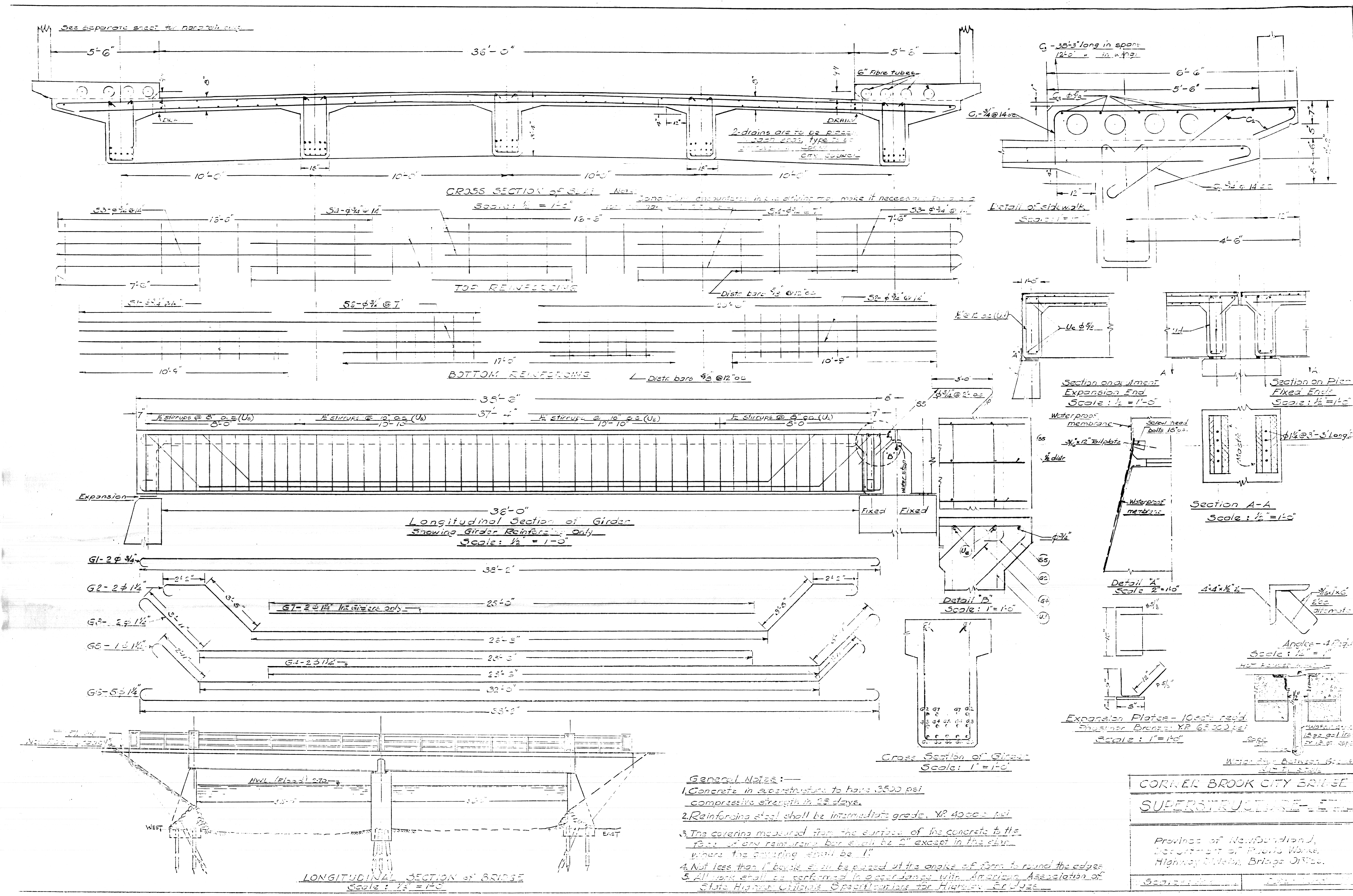


CORNER BROOK CITY BRIDGE

SUBSTRUCTURE

Province of Newfoundland,
Department of Public Works,
Highway Division, Bridge Office.

Scales: As shown. | Date: March 1956



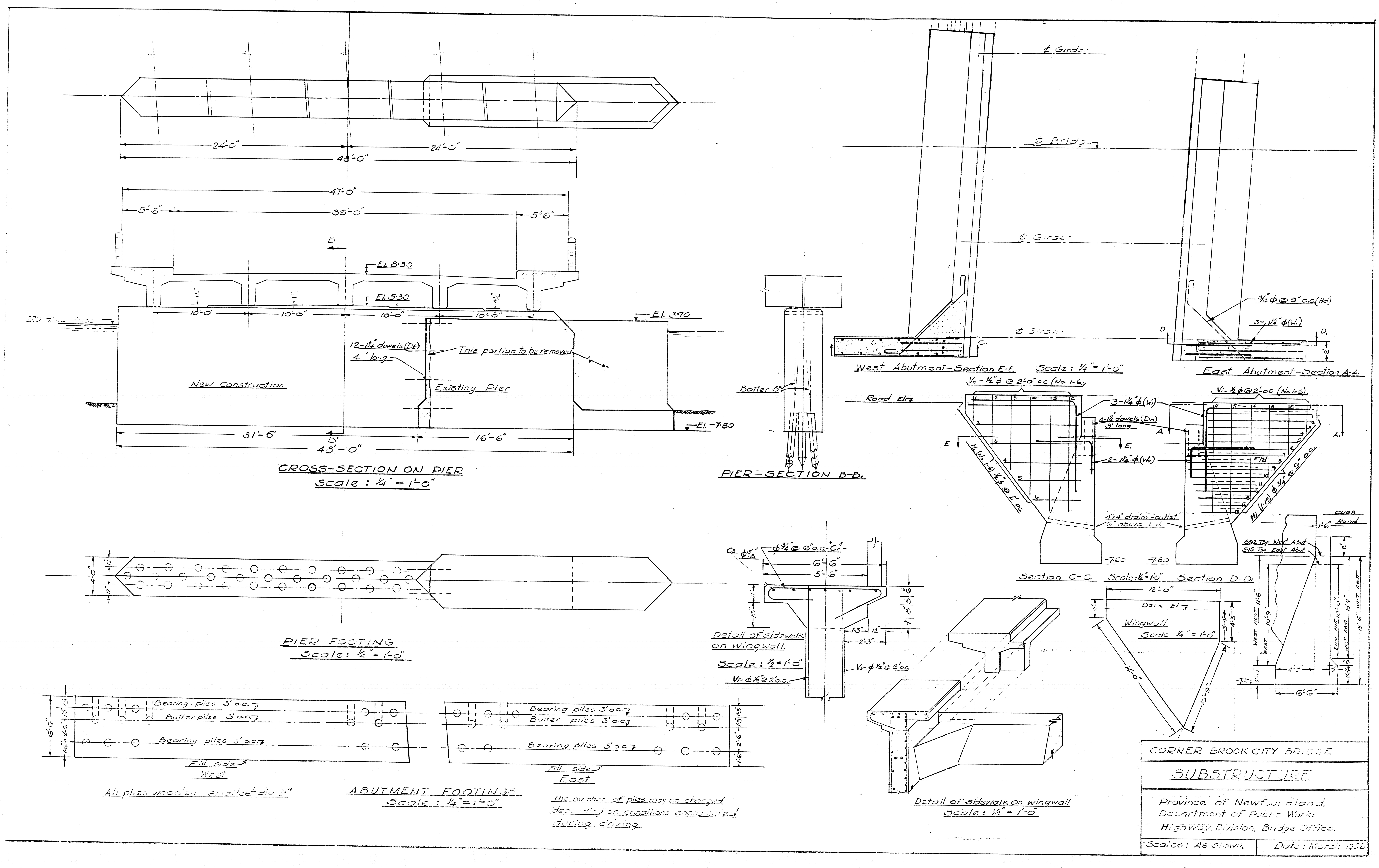
General Notes:—

1. Concrete in superstructure to have 3500 psi compressive strength in 28 days.
2. Reinforcing steel shall be intermediate grade, Y.P. 40000 psi
3. The covering measured from the surface of the concrete to the face of any reinforcing bar shall be 2" except in the slab where the covering shall be 1".
4. Not less than 1" bevels shall be placed at the angles of form to round the edges
5. All work shall be performed in accordance with American Association of State Highway Officials Specifications for Highway Bridges

CORNER BROOK CITY BRIDGE

SUPERSTRUCTURE-DETAILS

Province of Newfoundland,
Department of Public Works,
Highway Division, Bridge Office.



CROSS-SECTION ON PIER
Scale : 1/4" = 1'-0"
New construction
Existing Pier
This portion to be removed
12-1¼" dowels (Dt) 4' long
El. 8·30
El. 5·30
El. 3·70
El. -7·80
PIER-SECTION B-B1
Batter 5"
PIER FOOTING
Scale: 1/4" = 1'-0"
Bearing piles 3' o.c.
Batter piles 3' o.c.
Fill side West
Fill side East
ABUTMENT FOOTINGS
Scale : 1/4" = 1'-0"
All piles wooden, smallest dia 8"
The number of piles may be changed depending on conditions encountered during driving
Detail of sidewalk on wingwall
Scale : 1/2" = 1'-0"
Detail of sidewalk on wingwall
Scale : 1/2" = 1'-0"
West Abutment-Section E-E
Scale : 1/4" = 1'-0"
East Abutment-Section A-A1
Section C-C1
Scale: 1/4" = 1'-0"
Section D-D1
Wingwall
Scale 1/4" = 1'-0"
Road El.
Deck El.
Curb
Road
4"x4" drains-outlet 6" above L.W.
3-1¼"ϕ(W1)
2-1¼"ϕ(W2)
CORNER BROOK CITY BRIDGE
SUBSTRUCTURE
Province of Newfoundland.
Department of Public Works
Highway Division, Bridge Office.
Scales : As shown.
Date : March 1938